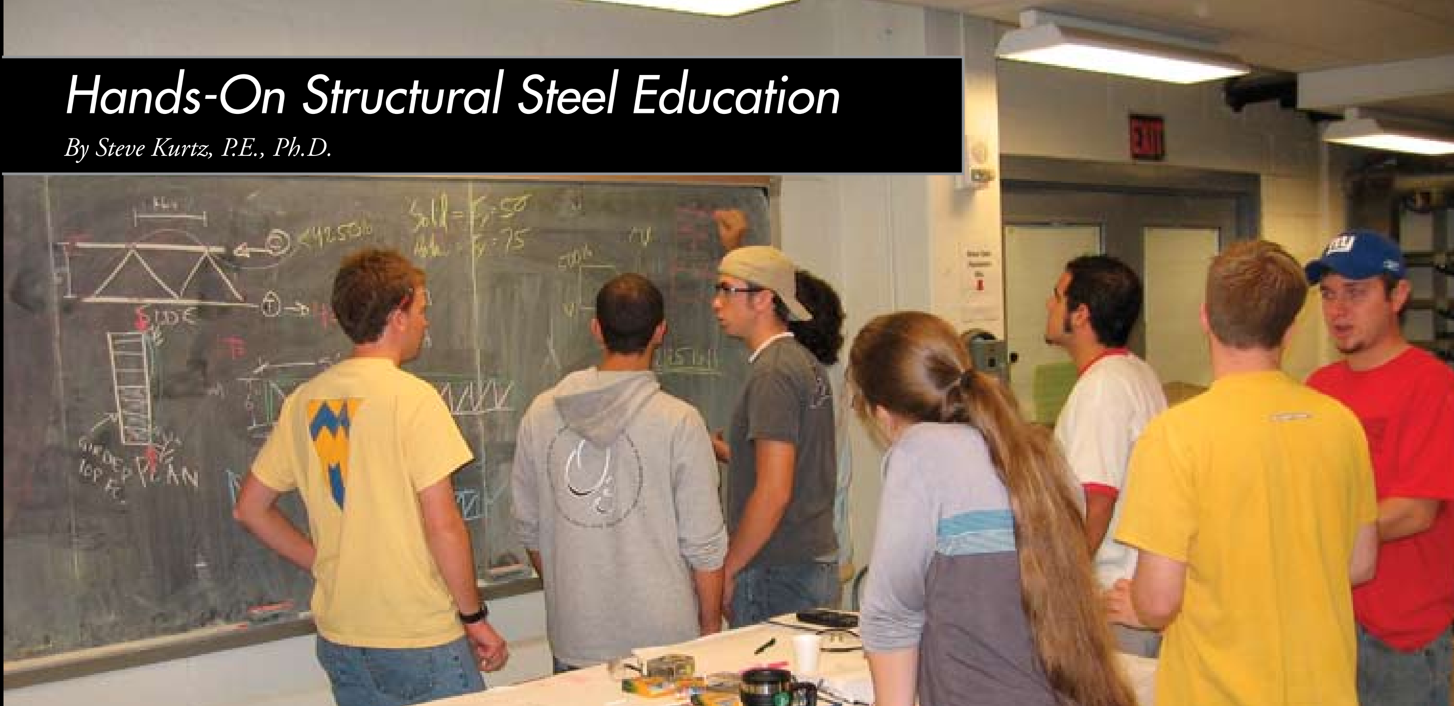
Hands-On Structural Steel Education

By Steve Kurtz, P.E., Ph.D.



LTB Lab, 1st Hour: Grasping the Concepts.

Education Issues

discussion of core requirements and continuing education issues

Structural Engineering has seen its presence shrink within civil engineering programs over the last several decades. As universities place greater emphasis on other areas of civil engineering such as transportation planning, construction management, environmental engineering, and GIS, there is less room in the curriculum for structures. At the same time, a greater proportion of the curriculum is now dedicated to public policy, economics, and political science, as well as other social sciences and humanities. Meanwhile, for more than three decades, the trend in engineering schools has been toward fewer total courses. All of these factors have led the typical civil engineering curriculum to reduce the number of mandatory courses from perhaps three or four courses in structural analysis, structural steel, and reinforced concrete, ten or fifteen years ago, to as few as one or two required structures courses, today.

The Lafayette College civil engineering program aims to offer students a high degree of choice, while still assuring that all graduates have had sufficient breadth to be called civil engineers. All students take required courses in surveying, transportation, construction management, geotechnical, structures, water resources, and environmental engineering, all of which have labs, for a total of six hours per week. The required curriculum also includes an intense junior design course devoted to four 3½ week-long design projects in geotechnical, structures, environmental, and water resources. Electives enable the structurally-oriented student to take five or six in structures. In contrast, students who lean toward environmental or water resources are likely to take the required structures course only. From this, these students must be prepared to do the design of a real-world structure (typically a single-story building) in the junior design course. At the same time, the first structures course must provide the theoretical foundations for the structurally-oriented student to take electives in structural dynamics, matrix structural analysis, advanced steel, concrete, timber, and masonry design. How can the first course do all of these things?

Supercharging the First Structures Course

At Lafayette, the first structures course is CE311 *Structural Analysis and Steel Design*. The mission of the course is seemingly unrealistic: to cover determinate structural analysis and steel design, two traditional three-hour courses, in a single, unabridged super-course. How the course accomplishes this is explained, not by magic, but by simple math: it meets six hours per week, yet still counts as a single class.

At Lafayette, the curriculum does not recognize credit hours. Instead, every engineering student must take 38 courses in order to graduate. Every course is equivalent in credit, whether it meets one hour per week or ten hours per week. Under this system, without restrictions on hours, civil engineering has eight required courses that feature three-hours of labs coupled with three hours of lecture, weekly. Overall, this has lead to a curriculum that is unusually hands-on. It also tends to be far more demanding on students than one would normally expect from a five-course semester. But this article is not about how one civil engineering department has found a creative way to overwork its students. This article is about how an extraordinarily hands-on laboratory experience greatly enhances education and motivates students to

Competitive Connection Calculations on a Welding Table.

LTB Lab, 2nd Hour: Beam Fabrication.

work extreme hours, while enjoying it. Based on responses from Fall 2004 student course evaluations, for example, the average student devoted an astounding 17.5 hours per week (with some devoting up to 30 hours per week) to this one course. Yet, for three consecutive years, the course has been the most popular required course in engineering, as measured by the same student course evaluations.

The mere fact that the CE311 structures course meets six hours per week does not explain its ability to effectively teach structural analysis and steel design. That is explained by a different way of looking at the laboratory experience. Conventionally, educators think of the laboratory experience as an enriching compliment to the classroom. The usual idea is that the lab is a place in which students are "exposed" to classroom-covered concepts already learned, benefiting students in a way that is not quite quantifiable (making labs the first "extra" cut from the curriculum). In contrast, the CE311 philosophy is that lab time and class time are equal partners in teaching the course's examinable learning objectives. The only difference between the lab and classroom is that the lab is better suited to topics that demand visual and physical understanding. While flexural buckling, lateral-torsional buckling, local buckling, connection limit states (among others) can certainly be taught in the classroom, they are more effectively taught in the laboratory.

The Highly Physical Classroom

The Structures Lab at Lafayette is considered to be a highly physical classroom, and it shares some attributes with ordinary engineering classrooms. For example, it contains blackboards and tables upon which students will vigorously perform calculations and create sketches. But when the calculations and sketches are done, the tables must be cleared for their primary purpose – they are actually welding tables. The tables are typically cleared in great haste because the students are under tremendous time pressure; the standard operating procedure is to challenge students to analyze, design, fabricate, and destructively test something new every week, all within three hours.

Beginning in the first day of lab, every student in CE311 (therefore, every student in civil engineering) becomes proficient in steel fabrication. Lab time regularly demands MIG welding, bandsawing, drilling, punching, shearing, and deburring, in addition to calculating, sketching, and note-taking. Students practice and learn steel fabrication, because the course philosophy is that students with physical experience learn physical problems quicker and more thoroughly than those who lack physical experience. For these students, residual stress is not a mysterious abstraction, but a recognizable physical problem that they will regularly take steps to reduce. These students feel and understand how load transfer takes place in a connection as second nature. For these students, stability bracing is more than a term; it is an essential tool that they use regularly. Above all, regular practice at creating designs makes these students creative designers.

Team Competitions

Team competition is a part of every lab. Each lab section, limited to no more than twelve students (and typically with about eight), works as a team to defeat the other lab sections each week. The first half of the semester consists of seven labs, each with its own lesson, homework, and competitive challenge. During the last seven weeks, the focus switches to a term project in which each lab section works as a team to design and fabricate a steel bridge for a competition held on the last day of class.

Labs in the first half of the semester are characterized by new lesson material, new skills, new homework, and the competitive challenge that binds it all together. Because the lab is used to teach new course material, students have their first experiences with bolted connections, welded connections, flexural buckling, lateral-torsional buckling, plastic bending, cables, arches, and overall stability in these lab lessons. The competitive challenges vary from analytical (e.g., predicting the failure loads of bolted connections) to design-build (e.g., design and construct a laterally-unsupported two-girder bridge) to computer-based design (e.g., maximize the stiffness-to-weight ratio of a SAP2000-based bridge design). Other lab challenges have included the design, construction, and eventual uniform-load-testing of an 8-foot-long masonry funicular arch.

continued on next page

LTB Lab, Final Hour: Celebrating a Lab Victory.

Term Project – The Steel Bridge Competition

Each year, the National Students Steel Bridge Competition (NSSBC), sponsored by ASCE and AISC, attracts more than 200 teams to regional competitions around the country, from which about 40 qualify for nationals. Though the rules and spans change each year, the basic premise of the competition is to design and fabricate a steel bridge with a span of about 20 feet that is structurally efficient, yet easy to construct. On the day of competition, each team assembles its bridge, which may consist of 30 or more size-limited members as rapidly as possible over a mock river. Subsequently, each bridge is load-tested with a pattern-load of 2500 pounds, while deflections are measured at several locations. The winning bridge is the one that minimizes the total "costs", which consist of construction costs and structural costs. Construction costs are determined by an equation that primarily considers the number of person-minutes required for assembly, while structural cost is determined by an equation that primarily considers the product of deflection and weight. In typical years, many teams at nationals will construct in less than five minutes, with midspan deflections of less than one inch.

Though many schools enter the steel bridge competition each year, to the author's knowledge, Lafayette is the only institution that holds an annual intramural steel bridge competition as a required part of the civil engineering curriculum. Since the fall of 2003, each lab section in CE311 has worked as a team to design and fabricate a bridge over the final half of the semester, culminating in a competition on the last day of classes.

The CE311 Bridge Competition – 2003. Courtesy of Sue Beyer, Express-Times.

While it might seem that one educational drawback of the bridge competition is that it is not a "real" project (please note that the term "real" may be a misnomer, considering that these projects are actually built, while most academic projects only exist on paper), this is actually its strongest attribute. Real-world design is regulated by typical details, conventional methods, and standard practice. In contrast, this competition produces unconventional connections, members, and styles whose reliability can never be taken for granted and demand a fresh investigation from the engineer.

The rules used for the CE311 bridge competition have evolved over the past three years. In 2003, the national rules were simply adopted verbatim. In 2004, the national rules were altered significantly for class-use in order to encourage more conventional design, which was thought beneficial to students. The changes were principally a different cost structure that strongly encouraged repetitive member use (i.e., each unique member had an associated cost in order to simulate the real-world benefits of repetitive members), while de-emphasizing erection time in the cost equation. The results were, indeed, quite conventional. End-plate moment connections using multiple bolts were common, for example. While these conventional designs and connections gave each student a feeling of having mastered the subject, the competition turned out to be less challenging and less exciting. Consequently, the format for 2005 was, again, based very closely on the national rules, but with several changes to enable an even wider variety of styles. Notable changes from national rules were made possible by conducting the competition on the department's reaction floor, so that the teams had the option of "purchasing" floor anchors to enable arches and suspended structures. In addition, unlike the national rules, the deflections under lateral loads factor into the team's score as much as vertical deflections, so that teams must give equal attention to the lateral system as to the vertical force resisting system (note the deck-level X-bracing on the bridge in *Figure 1*).

Figure 1: The CE311 Bridge Competition – 2005.

The steel bridge project, more than any other aspect of the course, explains why students are willing to work extreme hours for something that is "just a class." The spirit of competition and rivalry is so excessive that the syllabus contains a "sportsmanship clause" to remind students to cheer for their team without being negative toward their opponents. It is common for each lab section to have its own theme music, T-shirts, and team logos. In 2005, one team wore eye-black for the competition, while in 2003 some team members wore miniature welding-clamp ear-rings for the competition. With all of this spirit directed toward a class, it is easy to see why this rigorous class is popular.

Eye-Black Adorned Students Display Team Spirit.

Essential Requirements

Not every engineering school can offer a course like CE311, but it is possible that others could if they met a few essential requirements. The most important requirement is that the institution must be strongly committed to hands-on engineering education, in general. Even at Lafayette, a program with eight required labs in civil engineering, this course has raised some eyebrows as casual observers question the vocational appearance of the course and wonder about the pedagogical value of steel fabrication. Fortunately, the overall institutional philosophy strongly supports hands-on education and radical ideas like these are ultimately supported. This support translates directly into the financial support for shop equipment, steel, and supplies. In addition, lab sections with less than twelve students, common in small schools, can be a substantial cost for a larger school. Finally, the success of the course depends strongly on how well lecture and lab are integrated. At Lafayette, these are naturally connected because one professor teaches all of the content in both lecture and lab, whether the topic is structural analysis, steel member selection, or welding, leading to the seamless integration of design with fabrication. It is the author's opinion that this course would lose much of its effectiveness if the labs were to be delegated to a graduate student or a technician.

The Bottom Line

Hands-on engineering education is more than just time-saving and motivating. While it is true that these students with physical experience pick up new topics quicker and are more motivated to learn, the most important impact is the level of their knowledge. The lab experience does more than give students meaningful application-level practice, performing calculations, sizing members, and designing connections. More importantly, the competitive challenges force students to synthesize their structural knowledge in order to execute an open-ended design. Once the project is completed, these students are able to critically evaluate and improve their own design and the designs of others, which is what engineering education is all about.▪

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