AC 2010-597: AN INTEGRATED GRADUATE LEVEL COURSE SEQUENCE IN STRUCTURAL ENGINEERING

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An Integrated Graduate Level Course Sequence in Structural Engineering

Abstract

This paper presents the development/re-structuring of a Masters of Engineering degree to provide for the greatest development of the skills and knowledge of students focused on entering the structural engineering profession. The program now includes a major design exercise during their second semester of study, represented by a graduate level capstone experience. This new capstone course is coupled with two other required graduate courses: 1) a newly developed applied finite elements (analysis) course, and 2) a pre-stressed concrete design course. This structure requires the students to be a cohort through these courses and allows them to develop learning communities, to gain experience on high stakes teams, and to work on a larger project than normally available in an academic setting. These integrated projects allow for leveraging of resources and just-in-time teaching and learning. The capstone design course is designed to function as a small structural engineering design office, where the class as a whole is developing alternative design solutions for a common client. A detailed peer design review will be required of the design teams, and time provided for individual teams to refine their designs based on peer feedback. The program will be assessed by comparing the performance of ME students in the core program courses that are part of both previous and new program requirements.

Introduction

Most masters programs have two tracks: one track preparing students for industry and another preparing them for research and future PhD. Though the needs of both groups have substantial overlap, the specific goals are different. In a large program, it is possible to provide significantly different learning experiences to the two groups and more specifically addressing their needs. The Structural Engineering program within the Department of Civil Engineering at Texas A&M University has two distinct Masters degrees: the Master of Engineering (ME) program and the Master of Science (MS) program. The MS program is research based, requiring the development of thesis research, while the ME program is the pre-professional degree. Both programs share a core set of courses and include an increase in basic structural engineering skills. However, while MS students are working on their thesis research, the ME students are taking additional courses focused on professional preparation. The dual tracks by no means limit a student's career path; it is simply a different emphasis.

Prior to the Fall of 2009, the ME degree differed from the MS only in (1) not requiring the writing of a thesis, and (2) students taking additional elective courses in engineering. While the additional knowledge gained through coursework is valuable, this degree structure was not specifically geared towards the further development of the critical skills needed by our pre-professional students. While all our graduate students need a sound foundation in theory, our pre-professional students require an understanding of how the theory will be applied in actual applications, whether they be in analysis or design, and the limitations of available tools and how to best utilize them. Similarly, all our students need to develop their abilities to integrate knowledge and skills from various sources to tackle a new problem, as well as how to pursue information that is not presented to them in a structured classroom format and work independently. The students in the research track, our MS students, have the opportunity to develop these skills during their research. That meant that students in the pre-professional (ME) program were not being provided with the opportunity to develop these skills. This new course sequence is intended to provide our pre-professional students the same opportunity.

This paper presents the development and re-structuring of the ME degree to provide for the greatest development of the skills and knowledge of students focused on entering the profession. The program now includes a major design exercise during their second semester of study, represented by a graduate level capstone experience. While advanced concrete and steel design courses at the graduate level have always and continue to include design projects, the nature of the courses limited the scope of the projects possible. Also, a new Applications of Finite Elements course has been developed solely for our ME students, in parallel with the existing theory-based course for research-focused students. While still grounded in fundamental principles, a major goal of the course is to explore the limitations of existing commercial software packages, particularly in the nonlinear range, and explore how to utilize those tools when stability concerns or nonlinear behavior are critical.

Use of active learning[1,2] , incorporation of technology[3], clustering/integration of courses[4], fostering learning communities[5-10], and capstone experiences[11] all have been used in first-year and other undergraduate programs with measureable success. While certain of these approaches have been attempted at the graduate level, there is limited information on their success. The authors are not aware of references demonstrating the effectiveness of combining these approaches at the graduate level, there is no reason to believe that the combination will not be as successful at the graduate level. It is expected that the application of these approaches will be equally, if not more effective at the graduate level than they are at the undergraduate level.

Summary of Degree Plan Common Coursework

Both MS and ME degree plans have the following common requirements:

1. Engineering Mechanics – 9 semester credit hours

- CVEN 633 Advanced Mechanics of Materials
- CVEN 657 Dynamic Loads and Structural Behavior
- A course in Finite Element Analysis (specific course varies for each degree)

2. Structural Element Behavior and Design – 6 semester credit hours

Students must take at least two of the following courses:

- CVEN 671 Behavior and Design of Prestressed Concrete Structures
- CVEN 659 Behavior and Design of Steel Structures
- CVEN 621 Advanced Reinforced Concrete Design
- CVEN 670 Behavior and Design of Composite Structures

The MS degree further requires one math course and two technical elective courses in addition to the completion of a thesis. The ME degree requires four elective courses and a capstone design course. As such, both degrees have theoretical courses as well as design courses. This paper focuses on the two new applied courses that are specifically geared towards structural engineering practice.

Description of New Courses

Applied Finite Elements Course

This course differs from traditional graduate courses, such as *Introduction to Finite Elements* or *Theory of Finite Elements,* both in what is included in the course **and** in what is left out of the course. Common elements of the *Intro* and *Theory* courses include: derivation of various types of finite elements; developing program segments to perform functions such as assembling a global stiffness matrix; comparing different integration techniques; etc. The *Applied* course starts with an overview of the process of finite elements; it is light on the theoretical development and emphasizes the uses of commercial finite element packages. The course **emphasizes:**

- The modeling of various *real* structures and structural behavior using these commercial programs; and
- The ability (and limitations) of these programs to replicate solutions to a variety of classical buckling, stress concentration, P-Δ, dynamic, and large deflection problems.

The goal of this course is to provide the students with a clear picture of the abilities and limitations of this powerful tool called ***finite elements*.** Sometimes this is accomplished through comparing theoretical solutions to those obtained from the computer; sometimes it is through comparing solutions obtained from different programs, and sometimes it is through comparing solutions obtained by two students (each thinking they are doing the same thing). Through this process, the students gain a healthy skepticism of computer generated results. Another difference between the theoretical and applied versions of the course is in the nature of the course projects. In the applied course the students work individually or in groups of two or three to model an existing structure. They are asked to compare finite element results under design loads to the building code requirements and then to explore the failure mechanisms for their chosen structure.

Capstone Design Course

While graduate design courses include a design project, they are typically very focused and limited in scope. The emphasis of those projects is to explore specific design issues that have been taught in that course for the material in question, and the projects typically have a specific structural system designated. While this is still an important part of the student's learning, students did not have a chance to explore taking a design from start to finish, including exploring what materials and structural systems would be most appropriate for the project.

The capstone design course is designed to function as a small structural engineering design office, where the class as a whole is developing alternative design solutions for a common client. At the beginning of the semester, the students work to identify the constraints of the problems including loading information, design criteria and potential structural systems to be investigated. After the information is compiled, the class selects several solutions to pursue in greater depth. The students work in smaller groups to explore specific design alternatives and compile information about the pros and cons of those selections. This begins the process of performing comparative system design, which is not part of any other course.

The teams present their preliminary designs mid-way through the semester, at which point a detailed peer design review is required of the design teams. As the teams review another design, the benefits are two-fold: they gain knowledge of another structural system and design issues as well as learning how to evaluate and provide constructive feedback to their colleagues. This process must be done in a timely matter so as to provide time for the individual teams to refine their designs based on the peer feedback.

Developing the Integration

Three graduate courses are coupled together: 1) an applied finite elements (analysis) course; 2) a pre-stressed concrete design course; and 3) a capstone design course. Master of Engineering students are required to take these three courses as a cohort. This structure allows students to develop learning communities, and to gain a real world like experience, including working on high stakes teams. This structure also allows instructors to assign larger projects than are normally available in an academic setting (i.e., one project bridging content from two or three courses). These integrated projects allow for leveraging of resources (some topics can be reinforced in another course, and at other times, a topic can be skipped in one course because it was covered in another), and the use of just-in-time teaching and learning among these three courses.

Linking these courses also allows the students to see a bigger picture. The analysis and design processes are cyclic in nature – often design courses do not emphasize the impact of cyclic design on the analysis; whereas, analysis courses rarely delve into the impact of design details on the assumptions made in analysis. Things such as: the ease (or difficulty) of modeling a built up section so that the computer model behaves in a way similar to the real structure; and the critical importance of documenting assumptions (e.g. a tension only bracing system depends on large L/r ratios) are obvious to faculty, yet often opaque to students. Increased connections among the students and courses should make the connections between and among the content more transparent as well.

Implementation:

The first cohort of students in new program structure started Fall 2009. The students are taking these courses in Spring 2010. In order to prepare, the Applied Finite Elements Course was offered on a limited basis to the previous cohort of students during Fall 2009. As the first offering of the Applied Finite Element course was underway, work began on developing the graduate design capstone course and considering how to integrate the learning experience between the courses when offered in Spring 2010. The design of the course began by identifying the specific learning outcomes for this course. During this process, the focus was on the developing the knowledge and skills would need upon entering a structural engineering design studio. The following learning outcomes were selected:

- Student will identify the relevant facets related to a given structural design brief
- Student will develop different structural solutions to a given design brief

- Student will analyze different structural systems and interpret the results
- Student will articulate her/his own engineering opinion and basis for judgment
- Student will identify engineering constraints related to culture, economics, and politics
- Student will compare technical features of alternative engineering solutions
- Student will compare nontechnical features of alternative engineering solutions
- Student will appraise group work done by others and write a comprehensive peer-review report
- Student will communicate and debate the merits of engineering design alternatives in both written and oral formats

After the learning outcomes were specified, the next step was specifying the course structure and content. The course would focus on a single major design experience, and the basic structure should allow for different structural systems to be considered at different years, depending on the expertise of the main faculty member in charge of the course. Project-based learning is ideally suited to this course as it is centered on a project that is characterized by a well-defined outcome, or deliverable, and an ill-defined task. This is exactly the environment expected in a structural engineering design office. The project itself is generally information-rich but the directions are kept to a minimum. The richness of the information is often directly related to the quality of the learning and level of student engagement and is expected to be especially rich in a graduate class that includes both national and international students. Additionally, the information is often multifaceted and includes background knowledge, graphs, pictures, specifications, generalized and specific outcome expectations, narrative, and, in many cases, the formative and summative expectations.

The design cycle of identifying constraints, preliminary design, design review and refinement, and project presentation have to fit within the fourteen-week semester. The following schedule has been selected for the first capstone course offering:

Week 1: Introduction
Week 2: Defining project constraints and goals; identifying technical requirements
Week 3: Exploring design alternatives and Conceptual design
Week 4: Preliminary design development
Week 5: Presentation of preliminary design (concept, alternatives, initial sizes)
Week 6: Refinement of preliminary designs, investigation of different solutions
Week 7: Refinement of preliminary designs, investigation of different solutions
Week 8: Final design development
Week 9: Final design development
Week 10: Project Presentations of finalized design
Week 11: Peer review of competitive design alternative
Week 12: Correction of errors and omissions arising from peer reviews
Week 13: Correction of errors and omissions arising from peer reviews
Week 14: Project Presentations and Course Wrap-up

This schedule models the design process in an engineering office and can easily be applied to different projects. Having a preliminary schedule is also important when starting to discuss how to integrate the learning experience between the different courses.

The program will be assessed by comparing the performance of ME students in the core program courses that are part of both previous and new program requirements. The programs that the two groups, ME students with standard requirements and ME students participating in new program, will vary only through the added capstone experience and through its integration with the pre-stressed and finite element courses. Although the students are not the same, the "typical" ME student is more or less the same allowing for a reasonable basis for evaluating the impact of the new degree structure.

Reflections

First Offering of Applied Finite Elements course – Fall 2009

Much was learned during a trial run of the Applied Finite Elements course (Fall 2009). As expected, the "teaching of software" was not really necessary. Although help menus and on-line tutorials are not of consistently high quality, once an overall structure is provided for what the computer "needs to be told", the students are willing to spend the time required to get the program to work.

On the other hand, the instructor had to demonstrate the need for benchmark programs through the following process:

- students solve a classical problem by hand;
- instructor solicits answers from the class;
- instructor assigns a computer solution of the same problem (different students use different programs);
- instructor presents a summary of the hand solutions (not always agreeing with the classical solution);
- students present (differing) computer solutions; and
- (as homework) students comment on possible reasons for differences AND the correct answer.

Graduate students do not view the computer as a black box. Nevertheless, they do not automatically question the results obtained with the aid of a computer.

The most popular component of the Applied Finite Element course was preparing a computer model of a real structure from a set of plans that were graciously provide by a former student. The students were glad to be working on something real. Students were asked to build a finite element model from the given plans. The teams were frustrated by the difficulty in communicating important details to the computer. The teams also were surprised that all the teams did not get the same results even when using the same program.

Expectations for Spring 2010

As the approaches being utilized have a sound pedagogical basis and have been utilized in undergraduate courses, we fully expect this new sequence of courses to enhance our students' learning. Students are highly motivated by tackling problems and experiences that they perceive as being real and directly applicable to their future careers. As such, gains are expected in both their technical skills as well as their ability to integrate non-technical considerations into their design process. Communication skills will be critical for the success of this course sequence, both for the students and the faculty involved. Students will need to effectively communicate both technical and non-technical considerations. They must also focus their communication depending on the audience: (1) their peers in other teams, who have not been working on the same structural system but do have a detailed knowledge of the project and (2)faculty members, who are acting as the supervising project engineer.

The integration between courses also allows for a richer learning experience to occur within only one semester, as well as emphasizing the importance of knowledge transfer and synthesis. Without leveraging off the knowledge and skills in other courses, the capstone experience would most likely require multiple semesters for the students to learn the required advanced analysis and design skills. Conversely, the capstone design studio provides an immediate "real" context for the material in the analysis and design courses.

Bibliography

1. Smith, K., J. Morgan, S. Ledlow, P.K. Imbrie, and J. Froyd, "Engaging Faculty in Active/Cooperative Learning," Frontiers in Education, FIE 2003, Boulder, Colorado, November 8, 2003.
2. Kenimer, A. and J. Morgan, "Active Learning Exercises Requiring Higher-Order Thinking Skills," ASEE, Nashville, TN, June, 2003.
3. Morgan, J. R., "Technology in the Classroom," 9th Annual TBEEC Conference on Enhancement of Curricular Content and Structure with Technology, Nashville, TN, November 20-21, 1997.
4. Everett, L., P.K. Imbrie and J.R. Morgan, "Integrated Curricula: Purpose and Design," Journal of Engineering Education, v. 89, no. 2, April, 2000.
5. Al-Holou, N, N. M. Bilgutay, C. Corleto, J. T. Demel, R. Felder, K. Frair, J. E. Froyd, M. Hoit, J. Morgan, D. L. Wells, "First-Year Integrated Curricula Across the Engineering Education Coalitions," Journal of Engineering Education, v 88, no. 4, October 1999.
6. Morgan, J., and Bolton, B. "An Intergrated Freshman Engineering Curricula," Frontiers in Education '98, Tempe Mission Palms Hotel, Tempe, Arizona, November 4-7, 1998.
7. Kenimer, A. and J. Morgan, "Building Community Through Clustered Courses," ASEE, Montreal, Canada, June 2002.
8. Malave, C., J. Rinehart, J. Morgan, R. Caso Esposito, and J. T. P. Yao, "Inclusive Learning Communities at Texas A&M University - A Unique Model for Engineering," Creating and Sustaining Learning Communities: Connections, Collaboration, and Crossing Borders, Tampa, FL, March 10-13, 1999.
9. Layne, J., J. Froyd, J. Morgan and A. L. Kenimer, "Faculty Learning Communities," Frontiers in Education, FIE 2002, Boston, Massachusetts, November 2002.
10. Morgan, J., J. Rierson and J. Rinehart, " A Freshman Engineering Experience – It Works!" 1998 Annual ASEE meeting, Seattle, WA, June 1998.
11. Todd, R. H., S. P. Magleby, C. D. Sorensen, B. R. Swan, and D. K. Anthony, "A Survey of Capstone Engineering Courses in America," 1995, Journal of Engineering Education, vol. 84, no. 2, p 165-174.
12. Burns, C. S. , "The Evolution of a Graduate Capstone Accounting Course,", Journal of Accounting Education, vol. 24, no. 2-3, pgs 118-133, 2006.