2006-164: DEVELOPMENT OF HANDS-ON EXPERIMENTATION EXPERIENCE FOR CIVIL ENGINEERING DESIGN COURSES AT SAN FRANCISCO STATE UNIVERSITY

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Abstract

This project will describe the revision of structural design courses, such as Reinforced Concrete Structures and Steel Structures, at San Francisco State University's School of Engineering, a major undergraduate degree granting institution. Development of hands-on experience for design courses originated with and was supported by funding from the National Science Foundation to set up an integrated undergraduate structural engineering laboratory. It aims to help students maximizing learning through hands-on experimentation, which will allow them to experimentally verify the theoretical and conceptual content of design courses. The goal is to motivate students to develop an understanding of why design specifications are written to avoid detrimental structural behaviors, through witnessing and verifying possible failure modes of structures. Implementation of a testing frame will significantly improve our undergraduate civil engineering curriculum, encourage student interaction, induce more commitment to learning, foster student curiosity, cultivate student creativity and bridge student connectivity between theoretical concepts and hands-on experience.

School of Engineering at San Francisco State University

Located in one of the most diverse, creative and globally connected regions of our nation, San Francisco State University has grown over the past 40 years to become a nationally and internationally renowned, comprehensive public institution. Of SFSU's total enrollment of around 29,200 students in 2004, about 60% are female and 40% are male. As is typical of comprehensive urban institutions, a large percentage of SFSU students work full or part time while pursuing their education. Many are re-entry students, returning to college after an extended absence, either to complete their original degree program or to obtain education and training in another field.

Reflecting the ethnically diverse composition of the urban area in which it is located, SFSU serves a significant number of minority students. Of those who declared their ethnicity in 2002-03, students of color comprise 63% of the undergraduate student body. By ethnicity, the student body is 37% White; 24% Asian; 14% Latino; 12% Filipino and Pacific Islander; 7% African American; 6% other and 0.8% Native American. Consequently, SFSU has been designated as a minority-serving institution by the US Department of Education.

The civil engineering program at SFSU offers four emphases: Structural Engineering, Geo-technical Engineering, Construction Management, and Environmental Engineering. The rigorous curriculum of the core program consists of 19 required engineering and 10 required science courses. Additionally, students must complete 6 engineering elective courses from one of the four emphasis areas.

Our advising and graduation audit system ensures that our students are proficient in required science courses: mathematics (through differential equations), probability and statistics, calculus-based physics and general chemistry. The following table illustrates the range of skills that students learn in these subjects and their applications within the civil engineering program.

Subject	Topics	Civil Engineering Courses
Mathematics (Math 226, 227, 228, 245)	Graphs, differentiation, integration, analytic geometry, vectors, sequences, series, differential equations, and matrix algebra	Engr 102: Statics Engr 300: Engineering Experimentation Engr 309: Mechanics of Solids Engr 308: Computer Methods in Engineering Engr 335: Surveying and Highway Design Engr 430: Soil Mechanics
Calculus-based Physics (Phys 220, 222, 230, 232, 240, 242)	Mechanics with lab, electricity and magnetism with lab, wave motion, optics and thermodynamics with lab.	Engr 102: Statics Engr 201: Dynamics Engr 309: Mechanics of Solids Engr 323: Structural Analysis Engr 430: Soil Mechanics
Probability and statistics (Engr 300)	Common methods of probability and statistics. Statistics applied in interpreting laboratory test results.	Engr 300: Engineering Experimentation Engr 308: Computer Methods in Engineering Engr 430: Soil Mechanics
Chemistry (Chem 115)	Atomic structure, periodicity, properties of molecules (structure, bonding geometry, polarity), elementary thermodynamics, elementary organic chemistry, with lab.	Engr 430: Soil Mechanics Engr 434: Principle of Environmental Engineering Engr 435: Environmental Engineering Design

Civil Engineering Curriculum

In order to demonstrate their proficiency in a particular area, students must meet the following learning outcome criteria: (1) the ability to present information clearly in both oral and written formats; (2) the ability to analyze and design systems, components or processes relevant to their field of specialty; (3) the ability to design and conduct experiments and/or field investigations, and to analyze and interpret data in their field of specialty; and (4) the ability to use modern engineering tools, software and instrumentation through hands-on experience relevant to their field of specialty (SFSU, 2003).

The major goal of the civil engineering curriculum is to give students a combination of theoretical background and hands-on practical knowledge. Instruction in structural engineering begins with Engineering Mechanics: Statics (Engr 102), then Engineering Dynamics (Engr 201). In Materials in Engineering (Engr 200), students learn fundamentals of material behavior, the concepts of stress, strain and failure. Instruction continues in Mechanics of Solids (Engr 309), adding more depth to student understanding of statics, as well as introducing the analysis of deformations. Mechanics of Solids (Engr 309) also provides preliminary instruction in designing for strength. Finally, Structural Analysis (Engr 323) further develops student proficiency in structural engineering, by expanding on the concepts of analysis for reactions, internal forces, and deformations, and provides instruction in the determination of loads, structural stability and basic concepts of design. Detailed methods for achieving strength and serviceability are covered in subsequent design courses taken by students who wish to develop a career in structural engineering.

Elective courses for students concentrating in structural engineering include: Steel Structures (Engr 426), Reinforced Concrete Structures (Engr 425), Wood Structures (Engr 427), Applied Stress Analysis (Engr 428), Foundation Engineering (Engr 431), Construction Engineering (Engr 439), Finite Element Methods (Engr 432) and Mechanical and Structural Vibrations (Engr 461). Most of these courses focus on basic design-oriented content to prepare students for practical experience. In their last semester, students enroll in a required two-course sequence, Senior Design Project (Engr 696/697), in which they: (1) engage in laboratory and field exercises and demonstrations; (2) discuss the selection of design projects, methods of research, engineering professional practice, ethics, and time management; (3) select, develop, schedule and complete an original design project; and (4) present the project orally and in writing. This advanced work is done with maximum independence under the supervision of a faculty adviser.

Existing Laboratory Experience

Our civil engineering graduates acquire the ability to conduct laboratory experiments and to critically analyze and interpret data in the areas of soil mechanics, solid mechanics, and fluid mechanics. This ability is acquired through two courses: Experimental Analysis (Engr 302) and Soil Mechanics (Engr 430). The students conduct these tests in groups, a process which promotes an understanding that experimentation often requires teamwork in project implementation and data collection. Each student writes a separate lab report, which explains the experimental activities, reports the raw data, presents the processed data, provides an analysis of the data and interprets the results. Students must compare their findings with a theoretical value and discuss the deviations. Both labs (Engr 302 and 430) comprise an open-ended project wherein students use their findings to design and build experiments for a specific purpose.

What is Currently Missing from the Civil Engineering Curriculum?

In order to be prepared to enter the civil engineering profession upon graduation, undergraduates must acquire: (1) depth of knowledge; (2) proficiency at engaging in teamwork; (3) experience in working with open-ended problems; and (4) a holistic approach to problems and to career development (Sabatini 1997). It is imperative to incorporate hands-on research into undergraduate teaching and curriculum development. Students learn best through hands-on experimentation, which allows them experientially to verify the theoretical and conceptual content of their courses (Jenkins, et. al, 2002). While our present structural engineering curriculum offers sufficient elective courses in design, it does not provide students with any hands-on experience to help them learn to visualize overall structural behavior and possible modes of structural failure due to external forces. The project aims to provide undergraduate students with such experiences by incorporating integrated structural laboratory experiments into all structural design courses. In addition, this proposal will also provide students with hands-on research experience while taking their design project courses (Engr 696/697).

The idea that undergraduates benefit from hands-on experience is widely known (Pauschke and Ingraffea, 1996). In developing this project, we have considered four models for incorporating such experiences into our curriculum: (1) providing a graduate research lab (Pessiki, Lu and Yen, 1994); (2) creating a lab which relies on computer simulation and small-scale models (Belarbi, et al., 1994); (3) offering multimedia-based instruction (Issa, et. al., 1999); and (4) building a full-scale testing frame for various hands-on structural experiments (Stahl and DeVries 2000).

As a non-Ph.D. granting institution with a mission to train industry-ready engineers and without access to a major research lab facility for undergraduate research and teaching, we have determined that Stahl and DeVries' model best fits our curriculum development needs. A testing frame will increase interaction between students in different years of study through various engineering courses, extend student opportunities in selecting senior design projects and most importantly, integrate not only structural engineering design courses, but also construction engineering and geo-technical engineering courses. Implementing a testing frame will significantly improve our undergraduate civil engineering curriculum, encourage student interaction, induce more commitment to learning, foster student curiosity, cultivate student creativity, and bridge student connectivity between theoretical concepts and hands-on experience. Ultimately, we expect that this project will improve our retention rate, particularly of students from underrepresented groups, since the research suggests that these students benefit most from a hands-on, experientially-based science curriculum.

Development Plan

We set up a testing structural frame and structural testing equipment at SFSU which can be used to test a beam subjected to bending, a truss subjected to multiple point loads, a wall panel with shear loads or with normal loads and a column with axial load with bending. The equipment will directly affect the following classes and student activities, described below in terms of both existing course content and revised course content, which will be adopted to prepare students to learn from the hands-on experiences that are a major goal of this project.

<u>Steel Structures (Engr 426)</u>: This course introduces students to a steel design method called the load and resistance factor design ("LRFD") method, currently through two seventy-five minute lectures per week. In their course evaluations and exit surveys, students expressed a strong desire for opportunities to visualize possible modes of failure of steel members, in order to improve their understanding of the design principles involved with steel structures. The revised course, if funded, will offer an additional three-hour laboratory section each week, which will include a hands-on experiment and a design session. The steel beam test will be conducted for students to observe the development of a plastic hinge, moment rotation and vertical deformation, and the behavior of beam local buckling. The various load combinations and the reduction factors will be explored under the LRFD specifications. The design session will concentrate on the development of steel design and construction documents, using both traditional calculation and computer software. Students will be expected to complete their

design of a typical steel office building in the design session. Students will also be required to present technical information in both oral and written form for each project.

Reinforced Concrete Structures (Engr 425): This course currently features three one-hour lectures per week and has traditionally been taught exclusively in the lecture format. The revised course, if funded, will offer additional one three-hour lab section per week, which will incorporate both a hands-on experiment and a design session. Experiments typically used will help students observe the development of flexural cracks, moment rotation and vertical deformation, the behavior of tension failure, compression failure, balanced failure, moment-curvature diagram, and the mode of shear failure. The design session will focus on the development of RC design and construction documents using both traditional calculation and computer software. Students will be expected to design a typical reinforced concrete parking garage building in the design session. Students will also be required to present technical information in both oral and written form for each project.

Wood Structures (Engr 427): This class currently is organized like Engr 425 as an exclusively lecture-based offering. The revised course, if funded, will offer an additional one three-hour lab section per week, which will incorporate a hands-on experiment and a design session. The revised course will also incorporate seismic design considerations with timber structures. A wood shear wall test will be conducted to explore the various possible modes of failure. The design session will focus on seismic design development for timber structures and preparation of construction documents, using both traditional calculation and computer software. Students will design of a typical residential timber building in the design session. Students will also be required to present technical information in both oral and written form for each project.

Construction Engineering (Engr 439): This class currently is organized the same as Engr 425. Students in this course will build formwork, place and tie the steel reinforcement, and place the concrete beam specimens to be tested in the revised Reinforced Concrete Structures (Engr 425) course. Students will also construct the timber wall panels and nail diaphragm with beams to be tested in the revised Wood Structures (Engr 427) course.

A new one-unit course (Engr 324: Concept and Principle of Structural Design): This one-unit course aims to cover the concept and principle of structural design which will teach students the definition of design loads, load path and the load combination. It introduces students how to derive the wind load and earthquake load. It brings students the concept of optimal design. This course is designed to cover enough information about the design criteria in respect to various structural materials, methods of design and design specifications. Because there is no need to cover these subjects in the structural design courses in the senior year, it will allow students to tackle more challenging design topics.

Integration and continuity of learning in an interdisciplinary learning environment

The project will bring students from both upper-division and lower-division classes together. It will help create bonds among students, develop team spirit, foster an environment that promotes peer relationships and also improve retention of students. The equipment will also bring students from different concentration areas, mainly structural engineering, construction management and geo-technical engineering and provide interdisciplinary interaction and engagement. This interdisciplinary learning environment will encourage students to explore projects within various concentration areas. Most importantly, this equipment will dramatically improve our curriculum in structural engineering.

Research for Undergraduate Education

The equipment will help us deliver research-quality experiments in undergraduate classes. Many design principles of reinforced concrete structures, steel structures and wood structures will be verified through the use of this equipment. For example, students will be able to experience the different behaviors of over-reinforced, under-reinforced and balanced reinforced concrete beams. They will learn to set up these tests themselves and will be able to verify the results with theories mentioned in their textbooks. Students will be able to fully digest the intent of design specifications, instead of simply reading about them in textbooks and design manuals. In addition, the equipment will bring up many interesting topics for senior students who wish to conduct experimental tests for their Engineering Design Project (Engr 696/697). Enhancements to senior projects as a result of this proposal have six objectives: (1) to develop an understanding of and facilitate intuition about the fundamentals of structural behavior; (2) to reinforce theoretical concepts through hands-on exercise, experiment and demonstration; (3) to introduce students to emerging technology in the structural engineering field; (4) to increase their understanding of structural engineering design concepts for different structural materials; (5) to prepare them for the design challenges of the future by addressing contemporary civil engineering problems and solutions; and (6) to improve their technical communication skills through written reports, experimental data analyses and presentation of the results. It is expected that this equipment will allow us to enrich our curriculum with many research-quality tests, which will in turn enrich the potential scope of senior projects for our students.

Providing Undergraduates Opportunities to Work in a Research Environment

All experiments are planned to include the participation of undergraduate students in the development of laboratory content. Students are an important part of the curriculum revision process at SFSU. This is especially true for development of the laboratory, which will be set up based on educational objectives to maximum learning, promote student participation and help mentor student development. The new opportunities afforded by the project are expected to have a strong impact on student choices for advanced study and career development.

Long-Term Effects on Employment and Practice of Graduates

At this time, SFSU evaluates the effectiveness of programs by sending out questionnaires to SFSU alumni five years after graduation in connection with required five-year program reviews. Graduates are asked about current employment, usefulness of the education received at SFSU, satisfaction with their major and the like. To assess the practical long-term value of knowledge acquired in the laboratory and revised courses on employment prospects and practice, PRI can add questions to the Alumni Survey to obtain data at the next scheduled surveys in 2005 and 2010. Alumni in civil engineering will be queried about the nature of their employment, and specifically about the relevance and usefulness of their training in civil engineering.

Conclusions

This project is to set up an integrated undergraduate structural engineering laboratory to revise our structural engineering design courses. It aims to help students learn through hands-on experimentation, which will allow them to experientially verify the theoretical and conceptual content of these courses. It is our goal to motivate students to develop an understanding of why design specifications are written to avoid detrimental structural behaviors, by witnessing and verifying possible failure modes of structures. The facility will increase interaction between students in different years of study through various engineering courses, extend student opportunities in selecting senior design projects, and most importantly, integrate not only structural engineering design courses, but also construction engineering and geo-technical engineering courses. Implementation of a testing frame will significantly improve our undergraduate civil engineering curriculum, encourage student interaction, induce more commitment to learning, foster student curiosity, cultivate student creativity and bridge student connectivity between theoretical concepts and hands-on experience. The project will bring students from both upper-division and lower-division classes together. This interdisciplinary learning environment will encourage students to explore projects within various concentration areas.

In order to disseminate our experience of the revised courses, we will conduct the following activities: (1) Encourage Students to Host Local Student Competitions. Our student professional organization has not been able to host various competition events due to the lack of adequate testing facilities. Students are encouraged to host these kinds of activities. This will foster student excitement to be more active in the engineering society. Students are also encouraged to present results of specific experiments at local professional engineer meetings. (2) Open the Laboratory for the School Preview and Summer Program for High School Students. The equipment will become an important part of our outreach events and summer program for promising high school students from backgrounds underrepresented in the engineering profession.

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