INTEGRATING NEES RESEARCH INTO ADVANCED ANALYSIS AND DESIGN COURSES

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ABSTRACT

A multi-institutional collaborative project, investigating soil-foundation-structure-interaction (SFSI), is being used to demonstrate collaborative research using the George E. Brown Network for Earthquake Engineering Simulation (NEES). The research plan involves computational simulation models as well as testing of a scaled bridge and complementary shake table, static, centrifuge and field tests of scaled bridge components to develop improved models of SFSI. To achieve one of the goals of the project, i.e. synthesize research and educational activities, two educational modules are under development. The first module explores the nonlinear behavior of individual reinforced concrete bridge columns and the second explores the effect of soil modeling assumptions on the analysis of a bridge bent. Each of these modules integrates results of analytical studies and experimental data with structural analysis and design concepts currently taught in the senior year or master's degree, to help students understand the limitations of modeling assumptions that they make. This paper discusses the two educational modules and the benefits and challenges associated with integrating experimental research and curriculum development.

Introduction

Researchers from nine universities around the United States are participating in a collaborative project to investigate soil-foundation-structure-interaction (Wood et al. 2004, Johnson et al. 2006). In addition to fulfilling its research goals, the project aims to demonstrate the experimental and information technology capabilities of the George E. Brown Network for Earthquake Engineering Simulation (NEES), the integration of computational and experimental simulation, the challenges of working in a geographically distributed environment, and the integration of research with course curriculum to more rapidly disseminate the results of the project into undergraduate and masters level education.

A continuous bridge on drilled shaft foundations (Fig. 1) is used as the prototype structure to study soil-foundation-structure-interaction (SFSI). This structure was chosen because it represents a common construction type in regions of moderate and high seismicity. Because of the size and complexity of the prototype system, the problem is studied through a

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series of four, complementary experimental programs: centrifuge tests of individual bridge bents to evaluate the nonlinear response of the soil and foundation system; field tests of individual bents to evaluate the linear response of the soil, foundation, and structure in situ; shaking table tests of a two-span model to evaluate the nonlinear response of the structure subjected to bi-directional, incoherent support motion; and static tests of bents and individual columns to evaluate size effects and strength degradation in shear under cyclic loads. In addition, computational simulations are used to interpret the data from individual experiments, relate test specimen response to the performance of the prototype system, and understand the limitations of the boundary conditions of the experiments (Wood et al. 2004).

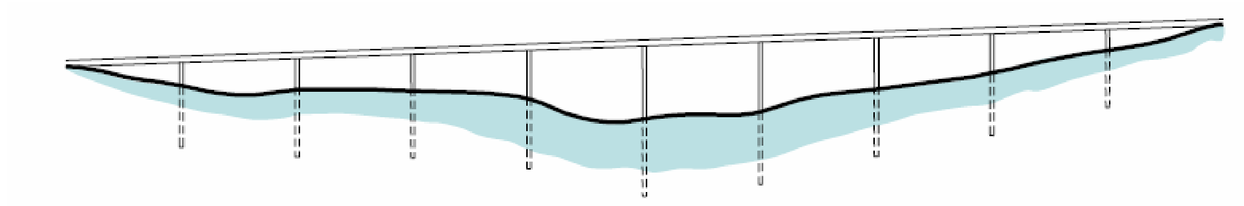

Figure 1. Prototype structure for studying soil-foundation-structure-interaction.

The NEES Education, Outreach, and Training (EOT) Strategic Plan (Anagnos et al. 2005) outlines eight strategies for achieving NEES education, outreach, and training goals and the NEES EOT vision of wide-spread dissemination and application of NEES research. First among these strategies is the integration of research with education. The EOT Strategic Plan cites several desirable outcomes of incorporating real world examples into curriculum as rationales for this strategy. These include providing context for theory, keeping curriculum current, and providing opportunities for extensions of topics as. In addition, a number of studies including those by Gempesaw et al. (2004) and Russell (2005) provide evidence of the importance of integration of research with education as a motivator for students to pursue advanced degrees. Finally, at a 2003 workshop to discuss educational opportunities within NEES, university participants identified data-rich case studies that complement theoretical concepts as one of the highest priorities for development.

To respond to this identified need, two course modules are under development as part of the dissemination plan for the soil-foundation structure interaction project. The first module, designed for an advanced course in concrete design, explores the nonlinear behavior of individual reinforced concrete bridge columns. The second module, designed for a course in indeterminate structural analysis or non-linear structural analysis, allows students to investigate the effect of soil modeling assumptions on the behavior of a bridge bent subjected to lateral loads. The web-based case study modules will consist of learning objectives, outcomes, explanations of how the modules fit into courses, selected design documents, computational and experimental simulation results with accompanying visualizations, video clips of relevant tests, potential follow-up activities and homework assignments, and assessment tools. The modules are being designed to provide students with tools to explore and discover underlying assumptions, limitations, and applications of engineering theories.

Motivation For Inquiry-Based Modules

Alternative teaching strategies have the potential to address many concerns related to the retention, motivation, and attitudes, as well as teamwork, communication, synthesis, and critical thinking skills of engineering students (ASCE 2003, NSF 1998). The class lecture, a common pedagogical practice of a majority of engineering professors, provides little opportunity for active learning and ignores the needs of certain types of learners. In particular, the "why" (Type 1) and what-if" (Type 4) learners earn lower grade point averages and drop out in greater numbers than the "what" and "how" learners (Bernold 2005). A survey of 100 junior and senior engineering students found that 68% indicate it is hard to absorb the material during lecture because they are busy taking notes (Bernold 2005). A summary of studies of learning styles of over 2500 engineering students indicates that 63% are active learners (versus reflective) and 67% are sensory learners (versus intuitive), yet engineering education is dominated by lecture style classes that emphasize theory and mathematical modeling over discovery and application (Felder and Brent 2005). Chickering and Gamson (1987) in their research on best practices for undergraduate education assert that teaching pedagogies that provide opportunities for active engagement with the material improve motivation and result in deeper learning. A lecture style course in which all students are expected to learn and progress at the same pace can cause students at the top and the bottom to be frustrated, leading to disillusionment, and in the worst case, dropout. One of the goals of the project is to develop inquiry-based modules that university instructors can use to engage students in activities that lead to a deeper understanding of theory and its limitations. An additional goal is to provide activities to complement course lectures, thus engaging students with diverse learning styles and backgrounds.

Although a number of studies have been completed that document the need for multiple teaching strategies to accommodate different learning styles and promote engagement (Smith et al. 2005), the application of active learning and inquiry to address the diverse needs of engineering students is less developed and the application literature is less available. We can gain additional insight from the extensive research and application in K-12 education. This literature provides a rich source of examples of how inquiry promotes engagement of all types of learners, allowing students to approach material on their own terms. Tomlinson (1999) in her work on differentiated instruction, discusses how students approach learning with different readiness, interests, and learning profiles; and teachers respond to this by differentiating content, process, and product. Differentiation allows students to take greater ownership of their learning by letting them control the pace, build on the knowledge they already have, and follow paths that fits their own learning styles. Recent research on how the brain works indicates that students retain and understand information if they are involved in learning situations in which they can connect new or unfamiliar concepts to those that are familiar (Tomlinson 1999). Harlen (2001) proposes that students often have pre-conceptions about a subject that are incorrect, and inquiry is an important tool for discovering these pre-conceptions and correcting them. Finally, inquiry-based activities naturally lead to differentiation because students can adjust the questions they want to explore, the level of complexity, the pacing, the materials, and the approach they take.

Purpose and Development of the Modules

Traditionally, exposure to research for an undergraduate or entry-level graduate student takes the form of a focused project outside of a formal classroom environment, under the direction of a faculty member or post-doctoral researcher. The research can occur during the summer on a full-time basis (for example an NSF-sponsored Research Experience for Undergraduates) or part-time during the academic year. The project may or may not be one that the student has proposed, and generally it is not directly related to courses he or she is taking.

The concept developed in this project for involving students in NEES research is quite different. Instead of a one-on-one mentor-student research model, the goal is to create a research environment for the classroom. By taking advantage of the data archiving capabilities of NEES, students can review experiments, run simulations, analyze data, and participate in the research process under the direction of a faculty member who is not directly involved in the research project and who may be located at a site remote to the research university. Students can perform the research, individually or in groups, as an independent study or as an extension of concepts being taught in a course.

Supplemental to the inquiry and active-learning goals of the modules, is a research goal. This is, the completion of the modules will provide a foundation for graduate students to join an ongoing research project with introductory research skills and basic knowledge of the problem being investigated (analytical modeling or reinforced concrete testing). The goals of the modules are to:

- integrate research into classroom instruction by using data from NEES experiments and simulations as support for case studies
- support inquiry and active learning in engineering courses
- provide a mechanism for students to explore soil modeling assumptions and limitations
- provide a mechanism for students to explore nonlinear behavior of concrete columns

Upon completion of the modules a student should be able to:

- discuss the problem using technical terminology familiar to the research community
- be aware of portions of the published literature in the field
- recognize common experimental test protocols
- compare and contrast the results of an experimental test to an analytical model
- explain the use of various experimental test instrumentation
- identify limitations in models and suggest possible means of improving their predictive capabilities

It is anticipated that the completed modules will be available in two forms: one for the student and one for the instructor. The student module will consist of learning objectives, outcomes, selected design documents, computational and experimental simulation results with accompanying visualizations, video clips of relevant tests, background literature, and student activities. The instructor module will augment the student module with explanations of how the modules fit into courses, potential follow-up activities, detailed information about the activities, and assessment tools. A general description of the two modules follows.

Nonlinear Column Behavior Module: Students use two methods to model the monotonic nonlinear behavior of a concrete column. The first is the concentrated hinge model prescribed by FEMA-356 (FEMA 2000). The second is a hinge modeled using established uniaxial linear fibers for the steel and concrete (Manders et al. 1988). In this second model, constitutive relationships used by concrete researchers are used to define the nonlinear property of each fiber. The results of the analytical model are then compared to test results obtained for the cyclic testing of two columns at Purdue University.

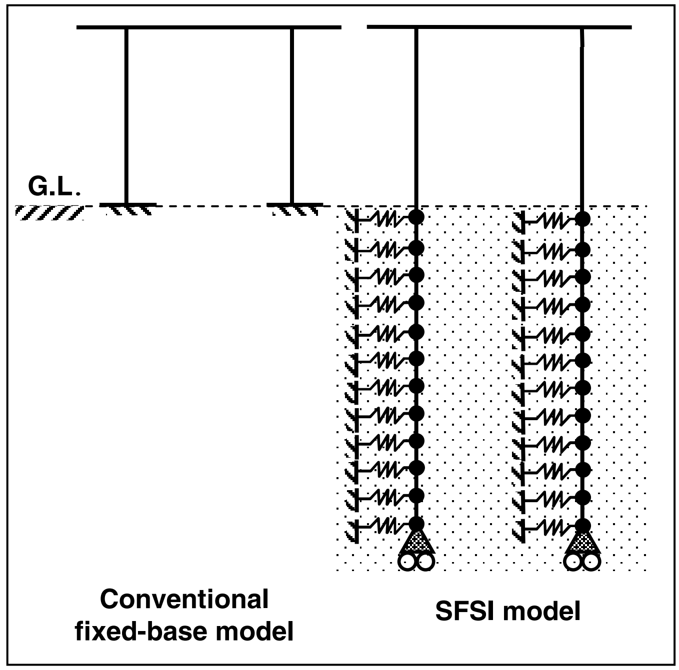

Figure 2. A conventional fixed-base model of bridge bent is compared with a model using soil springs.

Soil-Foundation Structure Interaction Module: In the module, students analyze a bridge bent and develop its pushover curve using different assumptions to model the soil and foundation (Fig. 2). Soil characteristics are modeled using non-linear springs with parameters developed from an LPILE analysis of the pile-soil interaction (Black 2005). The pushover curve developed from the analysis is compared with data collected from a pull over test of a scaled model of the bent at the University of Texas at Austin. Other linear and nonlinear characteristics and behaviors of the bridge bent can also be explored such as its period of vibration and location of hinges.

Considerations and Challenges in Developing and Adopting NEES Modules

The development of curricular modules from NEES experiments requires consideration of structure of existing engineering programs and poses a number of challenges. These have been grouped into three categories: lesson plan, research and development, and distribution and adoption.

Lesson Plan

The first challenge in designing a module is defining the audience. Engineering curriculum varies at different universities throughout the country (and around the world). Topics such as nonlinear analysis, finite element analysis, or structural dynamics could be taught in senior electives or in graduate courses. Students' prerequisite knowledge will vary depending on where these topics are taught in the curriculum. Students at different levels will have varying experience with simulation software for analysis and visualization, thus computer applications used in the modules must be straightforward and easy to learn, yet adaptable to more challenging interpretation.

A second challenge centers on the length and complexity of the activities. It is safe to say that most faculty feel that there is more content to learn in every course than there is time for students to learn it. Instructors constantly make choices about what to add and what to eliminate from a course, as well as what to deliver as lecture and what students should discover on their own. To make a module more attractive for adoption, it is important that it be designed with the flexibility to vary the amount of class time and out-of-class time students engage with the material. One instructor may be able to spend only one class period introducing the module and then assign it as a project. Another instructor may decide that the concepts or outcomes are so important that she is willing to devote several classes to the activities and discussions.

While only a few masters level programs are accredited by the Accreditation Board for Engineering and Technology (ABET), most undergraduate programs are. Therefore, modules will be more attractive to instructors if ABET outcomes are considered during the development of activities and assessments. ABET outcomes (ABET 2004) related to the design and conduct of experiments, analysis and interpretation of data, engagement in lifelong learning, teamwork, and use of techniques, skills and modern engineering tools are particularly suited to the integration of research with classroom instruction.

Computer-based or web-based modules present advantages and disadvantages. Computer-based activities allow students to work with more complex models, manipulate real data, use self-paced instruction, and interact with dynamic visualizations. On the other hand, although computers are ubiquitous in engineering education, it cannot be assumed that all universities or students have the access to the same equipment or software. Any software or visualization packages that are used in the modules should run on most standard desktop computers. The Apple/PC incompatibility continues to make this a challenge. Web-based modules can support the posting of answers to homework and test questions to allow for student self assessment. However, issues of security also must be addressed. If homework and exam solutions are stored as part of the instructor module, some means of limiting access must be developed to maintain their integrity. One solution is to require some form of password and user verification.

Assessment poses challenges with the evaluation higher level learning skills such as critical thinking or synthesis. Examples are comparison of the predicted results from models with experimental data, or identification of model limitations. Whereas assessment of factual knowledge (e.g. what is the purpose of a strain gage?) is generally straightforward, accurately assessing the ability of students to correctly use appropriate terminology in explaining a phenomenon is more challenging. As part of the instructor module, rubrics to assist with assessment will be developed.

Research and Development

A particularly challenging aspect of the module development has been the sequential nature of experimental research. While data on specimen design and loading protocols are available from early in the project, data on structural response are not available until the experiments are completed. The raw data collected in experiments must be verified and processed before datasets are available in a form suitable for analysis. Experimental plans and test specimens continually evolve to accommodate issues as they arise in any research endeavor. In this project, most modifications had little to no impact on the theoretical development of the educational modules or the experimental data that will be used for comparison; however, some modifications required revising and repeating analyses. When the field site for testing the individual bents needed to be changed, the soil profile changed, resulting in a change to the parameters of the predictive analytical model. Additionally, actual material strengths tested varied from the nominal strengths used for initial analytical models.

These types of issues make it difficult to develop the curriculum modules in parallel with the experimental research. Instead much of the module development needs to occur once the reports on the experimental work have been completed. A stepped procedure has been used in this project. During the first year, the authors attended project meetings to gain an understanding of the experiments and the data they will produce. During the second year, the theoretical basis for each of the educational modules was developed. Now that the experimental phase is complete, data, simulations, videos, and photos will be reviewed for inclusion in the modules. Initial models will be revised to consider final revisions to material properties, geometric configurations, and testing protocols.

Another challenge that is characteristic of most NEES projects is collaboration with colleagues at geographically distributed sites. This project supports a large team consisting of more than 30 faculty and student researchers. Strategies such as video conferencing, teleconferencing, extensive use of email, and development of project web sites are essential elements of project communication. When possible, team members take advantage of attendance at professional conferences to arrange face-to-face project meetings. Attempts were made early on to use the NEESgrid CHEF tool to facilitate collaboration. CHEF provides a secure web-based collaborative work environment with functions for scheduling, archiving, discussions forums, text chat, and data viewing and sharing. At first several team members tried posting to it, but because it required everyone to spend time learning a new software package, most team members found it easier to use systems of communication that they were already familiar with such as emails with attachments. Email has the problem of generating too much email traffic if all correspondence is sent to the whole team, but possibly loosing key information when correspondence is restricted to just a few team members. Collaborative tools such as CHEF alleviate this problem by archiving correspondence and discussions and facilitating the organization of postings and the viewing of data. Partly because the project web sites are not secure, project web site postings tend to consist of completed reports and conference papers. However, to enhance collaboration, team members need to have access to data, drawings, photos, and analytical models and their results continually throughout the project. Perhaps the real underlying challenge is that collaboration on this scale is new to the earthquake engineering community. The research community will need to undergo a culture change before its members make effective use tools and best practices for collaboration.

Distribution and Adoption

The issue of dissemination and adoption is particularly challenging. While many innovative activities, laboratories and curricular modules have been developed in the past, it is not clear how many have actually been adopted. Barriers for adoption include: how and where to obtain the material, incomplete or confusing instructions on activities, having time for an instructor to try an activity out and see how it works before students use it, not having the indepth prerequisite knowledge to fully understand an activity, and downloading a software module that doesn't work properly on the instructor's computer. The National Science Foundation has supported the development of several digital libraries including the National Science Digital Library (NSDL) (http://www.nsdl.nsf.gov/indexx.html) and the National Engineering Education Delivery System (NEEDS) (http://www.needs.org/needs/), where science and engineering learning materials can be archived. In addition, NEES plans to dedicate a portion of its resources to archiving NEES related educational materials. However, many university faculty are not familiar with these online resources, thus additional strategies for publicizing the availability of materials must be employed. Under consideration are: (1) direct contact with universities around the country to have faculty pilot the modules in their courses, (2) developing a partnership with a textbook so that a module could be bundled with the text or hosted on a website that contains supplemental materials for the book, or (3) hosting workshops for faculty in which the modules are demonstrated.

Faculty development is essential to the successful adoption of the modules. Many instructors are not familiar with strategies and motivations for active or inquiry-based learning. Without background knowledge of these innovative teaching methods, it can be frustrating for instructors to envision the use of such methods and to appreciate the nuances of various available course materials. Research on best practices in K-12 professional development (Maldonado and Victoreen 2002) indicate that successful professional development requires sustained contact, collaborations among participants, and follow up support. While there is no magic number for the minimum of hours of professional development needed to impact teaching, a survey of more than 5000 K-12 teachers (Parsad et al. 2001) indicated that teachers who participated in eight or more hours of professional development in a particular content area were more likely to report that it improved their teaching than those who participated in less than eight hours. For major reform, a significant time commitment is required to make real change. The authors believe comparable time commitments are required for higher education.

Penberthy and Millar (2002) studied the attempted "hand-off" of course innovations from one instructor to another without adequate motivation, faculty development, or support, which resulted in frustration for both the adopting faculty member and the students. Particularly vexing to the instructor was the inadequate documentation of details of implementation. An instructor adopting an activity needs clear instructions on the goals of an activity, how to best execute it, and how long it takes to ensure that it works well. Penberthy and Millar recommend training prior to, and during, the implementation of an innovation. An instructor who is able to discuss his experiences with the innovation and brainstorm fixes to aspects that are not working, is more likely to be successful. One strategy to accomplish this would be to develop an online discussion group for faculty who are adopting NEES modules.

Assessment of module adoption and success is as important as dissemination. Assessment data will be useful in modifying the modules to improve their effectiveness and to develop recommendations for development of future NEES educational modules. Strategies such as collecting feedback from pilot instructors, monitoring of an online discussion forum, and surveying of students and instructors are all being considered.

Conclusions

This, as well as other NEES research projects, has the potential to provide a much needed resource to engineering education: educational materials that promote inquiry and active learning. These types of materials help students and faculty support multiple learning styles. In addition, they promote engagement with the subject matter, which leads to deeper learning and better retention. The data archiving and remote access capabilities of NEES provide a natural starting point for data-rich case studies desired by engineering faculty, and for developing a research environment in the classroom where experimental test results and computational simulations are used to support the theory being taught. Curriculum module considerations and development challenges were identified in the areas of lesson plan, research and development, and distribution and adoption. These include addressing diverse audiences, prerequisite knowledge, computer skills and equipment, and faculty backgrounds and needs. The sequential nature of research poses challenges with access to data and research results during the development of curriculum modules. The geographically distributed and collaborative aspects of NEES research projects require additional attention to research team communication. The successful dissemination and adoption of materials requires faculty development and ongoing faculty support.

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