A PROJECT-BASED INTRODUCTORY GEOTECHNICAL LABORATORY COURSE

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ABSTRACT

Nearly all undergraduate civil engineering curricula include a geotechnical laboratory course. The traditional format consists of conducting individual isolated laboratory tests, often on manufactured samples, with separate weekly reporting for each test. Although this format provides hands-on experience with standard test methods, it does not teach how these tests are integrated into the design process. More importantly, it does not provide the student with any experience in the broader challenge of characterizing a real site, and thus presents an overly sanitized picture of the site characterization process. In order to address these pedagogical shortcomings, the authors and their colleagues have developed an alternative format which consists of a project-based laboratory course that is taught after completion of the associated lecture course. This paper presents the rationale for the course design, describes the course organization and content, and provides a qualitative assessment through authors' experiences in teaching undergraduates using this approach.

BACKGROUND

The need to redefine and improve undergraduate education to meet the needs of the 21st century has been a significant area of scholarship and discussion over the last two decades. The Boyer Commission (1998) produced a comprehensive work articulating the need for a new approach to undergraduate education, and addressed the need for institutional changes across all disciplines. In addition, there have been a number of calls for reform in civil engineering instruction (e.g. Al-Khafaji et al 1998, Roesset and Yao 2000, Sack et al 2000, Nehdi and Rehan 2007) and even more specifically to the teaching of geotechnical engineering (e.g. Seidel and Kodikara 2000, Steenfelt 2000, McDowell 2001). A key element in many of these proposed reforms is to move from educational models centered primarily on the transmission of knowledge to those that incorporate experiential and hands-on learning.

These reform efforts are sometimes characterized in terms of Bloom's Taxonomy of Educational Objectives (Bloom, 1956), which illustrates a progression from the basic objectives of knowledge and comprehension to the more advanced objectives of application, analysis, synthesis, and evaluation. A well-designed curriculum moves stepwise up this progression.

The authors and their colleagues have applied some of these principles to the required undergraduate geotechnical engineering coursework at California State Polytechnic University, Pomona (Cal Poly Pomona), and have introduced innovative methods of teaching these courses, specifically the laboratory component, as described in this paper.

APPROACHES TO INTRODUCTORY GEOTECHNICAL ENGINEERING CURRICULA

The Accreditation Board for Engineering and Technology (ABET) civil engineering program criteria includes an expectation that "graduates can … apply knowledge of four technical areas appropriate to civil engineering." Nearly all ABET-accredited BSCE programs include geotechnical engineering as one of these four technical areas, and thus have associated required coursework.

The most common format is a single required course that consists of concurrent lecture and laboratory components. The lecture introduces the principles of geotechnical engineering, and weekly lab sessions typically consist of conducting standard tests associated with that week's lecture and preparing a written report describing the test results. The instructor provides the soil samples, often selected to illustrate a particular aspect of soil behavior. This format is intended to reinforce the lecture concepts, and to provide direct hands-on experience with soils and standard test equipment. It also supports the ABET program requirement to "conduct civil engineering experiments and analyze and interpret the resulting data." Sutterer et al (2005) provide additional insights on the educational objectives of geotechnical engineering laboratory courses, and observe that these labs can serve many different program goals ranging from inspiring students to pursue advanced geotechnical research to preparing students for civil engineering practice. The relative importance of these various goals at each institution often impacts the way laboratory courses are taught, and how they support the program educational objectives.

As a result of this increasing sensitivity to the connection between lab activities and program educational objectives, some institutions are using other approaches for geotechnical laboratory courses. For example, several universities have incorporated hands-on field trips to construction sites and/or field soil investigation and sampling (Meade et al 2000, Fiegel and DeNatale 2000). Others incorporate projects (Evans and Ressler 2000, Sutterer 2003) or case histories (Akili 2009) into their geotechnical coursework. However, these projects and case histories are typically used in upper-division elective design courses or senior-level capstone design classes, and these features are not necessarily incorporated into the required introductory courses. Hernandez and Vitton (2009) present an interesting approach of building an introductory geotechnical course around integrated laboratory workshops.

GEOTECHNICAL ENGINEERING CURRICULA AT CAL POLY POMONA

The Civil Engineering Department at Cal Poly Pomona was founded in 1961, and now offers both BSCE and MSCE programs. Consistent with the university's educational philosophy and mission, the BSCE program has always placed a strong emphasis on producing practice-oriented graduates and thus includes a strong emphasis on hands-on and design-oriented activities such as laboratory courses. The university and the department consider "learn by doing" to be a core value and a centerpiece of our educational philosophy.

Cal Poly Pomona uses the quarter system, with each term consisting of ten weeks of classes followed by one week of final exams. The BSCE degree requires a total of 198 quarter units of coursework, which is equivalent to 132 semester units, and has always included a geotechnical engineering component. Prior to the late 1990s, the required geotechnical coursework consisted of two courses taken in sequence:

- CE 323/323L – Soil Mechanics and Soil Mechanics Laboratory (3 quarter units) consisted of a traditional introductory geotechnical engineering course with a concurrent laboratory course. This laboratory was taught using the traditional approach described earlier.
- CE 324 (later CE 424) – Foundation Engineering (3 quarter units) covered basic foundation engineering

First Iteration – Project-Based Laboratory

During the early 1990s, the Civil Engineering Department conducted a review of its undergraduate curriculum and facilities. In the interest of involving the Department's major constituencies, the review team included the Industrial Advisory Council, which played a key role and provided significant input. One of the council members, a practicing geotechnical engineer, correctly observed that the CE 323L course presented a very narrow and overly-sanitized picture of the site characterization process, and did little to instruct students on how the various tests form part of the geotechnical design process. The various soil tests appeared almost to be ends in themselves rather than part of a much larger process. He thus suggested incorporating a design project, which would help overcome these shortcomings and strengthen the laboratory experience.

Following up on this suggestion, the geotechnical faculty introduced a small design project into CE 323L. Rather than providing soil samples for the various tests, the Department purchased basic hand augers and soil samplers, and restructured the course so that the early lab sessions consisted of drilling exploratory borings at a site on campus and obtaining soil samples for the subsequent lab sessions. During the later sessions, the students performed standard laboratory tests on these samples and used the resulting data to complete a design project.

This change represented a significant improvement to the course, resulting in educational outcomes that were more consistent with university and department objectives. The students gained a much better understanding of the design process, as well as gaining first-hand experience with the inevitable vagaries of characterizing a real soil profile. However, because the laboratory was still conducted concurrent with the lecture, the students were not well-prepared to do the necessary synthesis. Thus, the intended objectives were not fully realized.

Second Iteration – Laboratory Mini-Capstone Course

Based on the experience gained from the project-based laboratory course, the faculty restructured the required geotechnical engineering coursework into a new three-quarter sequence such that the laboratory course follows the lecture courses, thus becoming a mini-capstone course:

- CE 325 – Geotechnical Engineering I (2 quarter units) covers introductory soil mechanics topics
- CE 326 – Geotechnical Engineering II (3 quarter units) continues the topical coverage from CE 325, and includes a small design project in which the instructor provides completed boring logs and test results.
- CE 327L – Geotechnical Engineering Laboratory (1 quarter unit) extends the earlier project-based laboratory concept and is clearly centered around geotechnical site characterization, testing, analysis, and design.

This new sequence was implemented in 1997, and continues to be required for all civil engineering undergraduates. The BSCE curriculum also includes a separate comprehensive capstone course in the form of a group senior project.

THE CE 327L MINI-CAPSTONE COURSE

As currently taught, the CE 327L Geotechnical Engineering Laboratory course at Cal Poly Pomona is intended to serve the following educational objectives:

- Reinforce the concepts learned in the CE 325 and CE 326 lectures by providing hands-on experience with real soils and standard tests
- Strengthen the students' understanding of the geotechnical site characterization process
- Provide experience working with others in a team environment
- Provide experience presenting the results of technical work in the form of a comprehensive written report and an oral presentation

The design project varies from quarter-to-quarter, and usually consists of the geotechnical analysis and design of grading and foundations for a proposed two-story building at a site on Campus. The students perform the field investigation and laboratory testing necessary to complete a geotechnical site investigation report including recommendations for spread footings and grading and compaction.

This project based course follows the typical process of a professional geotechnical site investigation. The basic phases are:

- Desk Study
- Preliminary Site Walk
- Field Investigation
- Laboratory Testing
- Analysis of Results
- Preparation of Recommendations
- Reporting

The class is divided into teams of three or four students. Each team remains intact through the entire course, prepares a single report containing investigation results and recommendations at the end of the term. The organization of the report is modeled after typical professional geotechnical site investigation reports for small projects. Finally, each team orally presents their work as if to a client.

Desk Study and Preliminary Site Walk

The course begins with an overview of the project requirements and a presentation of safety procedures for both field and laboratory operations. Immediately following this overview, the desk study commences. It starts with an overview of a geologic map of the local area in which students are required to locate the site on the map and identify the geologic deposits they expect to encounter on the site. In addition to the geologic map, the instructor provides a geologic hazard report and map prepared by the state geological survey. This process often relies on skills the students learned in the engineering geology course, which also is required for all civil engineering majors.

The first class meeting also includes a preliminary site walk, during which the students evaluate the site for accessibility, hazards, and current land use. They also use this time to start preparing their drilling and sampling plan. At the end of this phase the students submit a draft desk study which they later incorporate into their final report as part of the description of regional and local geologic conditions.

The typical sites used on campus consist of recent quaternary mixed alluvial fan/valley deposits. The soils are predominately clayey or silty sands, with some clay seams, and some gravely layers. The water table depth varies from 20 to 30 feet.

Field Investigation

The field investigation is accomplished over two laboratory periods, generally one week apart. The primary drilling method is hand augering with a 4-inch bucket auger, and each student team is expected to complete one boring to a depth of 10 to 15 feet during each lab session. Before drilling, each team submits a drilling and sampling plan indicating the location of borings and planned sample type and frequency. Using the bucket auger, they are able to retrieve disturbed bulk samples. Students are also able to retrieve intact samples using a 2.41 inch inside diameter thick walled California sampler, a commonly used sampler in this area. The California sampler employs brass liner rings enabling retrieval of a relatively undisturbed sample. The California sampler is driven using a 30 lb hammer dropped 12 inches. The number of blows required to drive this sampler 12 inches is recorded and converted to an approximate Standard Penetration Test (SPT) blow count using a locally developed correlation. The students collect samples, perform field identifications of the soils, and maintain boring logs while in the field.

The hand augering equipment is inexpensive, easy to operate, and relatively safe, and thus is a very effective tool for students to use in field investigations. The auger bucket is 6 inches long, allowing students to retrieve samples every 6 inches without mixing soils from different layers. This makes it very easy for students to identify different soil layers. The three main drawbacks for this method of drilling and sampling are 1) it is difficult to sample gravelly soils, 2) boring depth is limited to approximately 15 feet, and 3) SPT tests are not possible. We avoid the first drawback by choosing sites with little or no gravely layers.

To mitigate the other shortcomings of hand augering, a trailer mounted solid stem auger rig is used to reach deeper depths and perform SPT tests. For each class, a single 30 foot deep solid stem auger boring is performed with approximately 4 SPT tests performed in the course of boring. The student teams take turns observing the solid stem auger boring and maintaining the boring log for a portion of this boring. In addition students are provided data from one or two cone penetrometer (CPT) soundings which have been previously performed at the site.

At the end of two 3-hour drilling and sampling sessions, the average student team has completed and logged two hand-augered borings each to a depth of 10 to 15 feet, collected four to six California type "undisturbed" samples, and collected 15 to 20 disturbed bulk samples. Additionally, the teams have a boring log from one solid stem auger boring to a depth of approximately 30 feet and four to five SPT tests from this boring. This deeper boring will generally reach the water table allowing determination of the water table depth at time of boring.

After completing the field investigation, the student teams submit draft boring logs based on their field notes and field identification of soils. These draft logs are often incomplete and have numerous errors, but make it relatively easy for the instructor to review and critique them. It generally takes the students two to three iterations to produce acceptable boring logs. However, these iterations are accomplished throughout the academic quarter as laboratory testing clarifies and corrects the students' field soil classifications. This iterative process is a very effective learning tool.

Laboratory Testing

The class then moves to the laboratory where students have access to standard test equipment and perform some or all of the following tests:

- Water content determination
- In-situ unit weight from undisturbed samples
- Atterberg limit measurement
- Sieve analysis
- Hydrometer analysis
- In-situ unit weight using sand cone method
- Proctor compaction test
- Direct shear test
- Consolidation test

The available laboratory time is adequate to perform water content on all samples collected, unit weight determination of all undisturbed samples, Atterberg limit measurement of two soils, and testing of one sample for each of the other laboratory tests. Generally student teams are performing two different tests each laboratory period.

The students are required to develop their own laboratory testing program in which they must determine which laboratory tests they will perform on which samples. In reality, it takes a significant amount of guidance from the instructor for the students to develop a viable testing program, but the interaction between student and instructor during the development of the laboratory testing program is another learning experience. For example, their selection of the sample for direct shear testing is particularly important. The students must use one of their few undisturbed samples and must recognize that the purpose of direct shear testing is to acquire strength parameters for the determination of bearing capacity. This forces the students to estimate the depth and width of footings in order to select a soil sample that is within the potential failure zone for bearing capacity. With proper guidance and mentoring from the instructor, the students are able to rationally select a sample for direct shear testing based on the requirements of the project. Similarly, the students must carefully select a soil sample for consolidation testing. The sample should come from the most compressible layer located within the zone influenced by footing loads, and, of course, must be an undisturbed sample.

This process of tying the laboratory testing program directly to the project requirements is a key pedagogical aspect of the class. It forces the students to understand the purpose of each test and the requirements of the project. They must then combine their understanding of each to develop an appropriate testing program. In reality they have to constantly modify their testing program as they increase their knowledge and understanding of the soil at the project site. Similar to the development of boring logs, this is an iterative process facilitated by the instructor.

Data Analysis

The data analysis is a three step process. In the initial step, students reduce their laboratory data for a given test, complete the data sheet, have it checked by a second student and submit it to the instructor. The instructor then checks the data for common errors and reasonableness and provides feedback. Generally the data are of sufficient quality to provide viable results, although computational errors are not unusual. The main purpose of this step is to catch simple correctable errors before the students need to apply the results. If the test data are unacceptably poor and no samples remain to conduct new tests, then students must either use data from another group or assume reasonable values for the needed soil properties.

The second phase of data analysis is to develop a model soil profile with the soil properties needed to complete analyses and make recommendations. This is the most difficult step of the analysis for the students. First they develop a simplified soil profile for the site using the boring logs they have developed, which can be very difficult for the alluvial sites used in the project. During field testing they have noted changes in the soil every 6 to 18 inches, but they have very few undisturbed samples and even fewer strength and compressibility tests. Once they have developed a simplified profile, they have to assign design soil parameters to the soils in the profile. This forces students to confront the variability of natural soil deposits and to apply engineering judgement (nascent as it may be) to establish design strength and compressibility values. Again an iterative interaction with the instructor can turn this seemingly daunting task into a significant learning experience.

The final analysis step is to perform the actual calculations to determine bearing capacity and settlement, and to make site grading recommendations. The students actually find this part of the process relatively easy since they are applying analysis techniques which they have used before in their earlier introductory geotechnical classes.

Preparation of Recommendations and Reporting

This portion of the laboratory class is relatively straightforward for students if they have kept up with their preliminary data analysis and developed a viable model soil profile. It can, however, be very time consuming. To reduce the time required to prepare the final report, the instructor provides a complete outline for the report and a grading rubric describing how the report will be evaluated. The advantages of saving all formal report writing until the end of the project are that it reduces the amount of writing students have to do earlier during the course and allows them to develop drafts of key portions of the report such as the geologic background, boring logs, and soil profile. This has the potential to increase both the level of synthesis students achieve as well as the quality of the final product. The disadvantage, of course, is students who do not keep up with the preliminary work will have great difficulty completing a quality report. In the authors' opinion the potential benefits of having a single final report greatly outweigh disadvantages. It does, however, require the instructor to provide feedback on early drafts of boring logs, test data, and model soil profiles. But the time required to provide such feedback is modest. In addition to the written report, students present their findings and recommendations to the instructor and their classmates in a short oral presentation.

STRENGTHS AND WEAKNESSES

After using this laboratory format for more than a decade, we have identified both strengths and weaknesses compared to the traditional format. Although we have not conducted any formal assessments, our experience indicates we have met the original objective of strengthening the students' understanding of the site characterization and geotechnical design processes. Placing the project-based laboratory in the academic term following completion of the associated lecture courses facilitates reaching higher levels in Bloom's Taxonomy, with the lecture courses working primarily at the knowledge and comprehension levels, and the lab course moving up to the application level with some elements of analysis, synthesis, and evaluation.

This format reinforces the concepts learned in the lecture course, but does so very differently than the traditional concurrent laboratory course. Students frequently bring their soil mechanics textbook to the lab sessions, and refer to it during the process of completing the project, a clear indication that the concepts learned in the previous courses are being reinforced.

This format also helps students develop their ability to draw conclusions and develop designs in spite of having incomplete and sometimes contradictory data. This skill is essential in the practice of geotechnical engineering, as well as most other branches of civil engineering. Although the students' ability to exercise engineering judgment is limited at this stage of their careers, the project-oriented laboratory provides an important introduction to this essential skill. It also provides much better experience in preparing written and oral reports, and is a closer simulation of the kinds of reports generated in engineering practice. Finally, this format appears to have strengthened the subsequent senior projects, some of which now use the soil exploration and sampling equipment obtained in the process of enhancing the geotechnical laboratory.

However, there also are some drawbacks to this approach, and mitigating them has resulted in other changes to the geotechnical engineering curriculum. The first drawback to the project-based approach is the additional laboratory time required for students to develop a laboratory testing program and to determine which soil samples to use for each test. The authors have attempted to mitigate this drawback by using multimedia pre-class presentations to introduce students to the purposes of each laboratory test and provide overviews of the testing procedures (Kitch 2009). Students are required to view these presentations and take an online quiz before each laboratory class. This technique significantly increases the number of students who come to laboratory class ready to start testing, thereby saving significant laboratory time.

The second and more challenging drawback is the loss of contemporaneous feedback from the laboratory experiences to lecture courses, which can initially make it more difficult for students to understand the physical realities associated with the lecture topics. The authors and their colleagues have mitigated this drawback using two techniques. The first is to use numerous in-class demonstrations of soil behavior, many of which are based on the ideas presented in the book *Soils Magic* (Elton 2001). The second technique is to create mini-labs within the lecture course. These mini-labs may be either out-of-class or in-class experiences. For example, the instructor provides students with a take home soils kit on the first day of class. The kit contains samples of various sand, silt and clay soils. During the course of the lecture classes, students are directed to perform home experiments to experience soil properties such as grain size and shape, apparent cohesion of partially saturated sand, and qualitative plasticity and compaction tests. The results of these tests are reported in simple homework questions. It also has become necessary to conduct one of the CE 325 "lecture" sessions in the laboratory where students gain hands-on experience with basic soil classification, with particular emphasis on the consistency and plasticity of clays and silts. We have found such timely hands-on student experience with soil behavior is essential, but this experience does not need to take the form of a traditional laboratory test program.

CONCLUSIONS

The project-based geotechnical laboratory course has been a significant improvement to the BSCE curriculum at Cal Poly Pomona, and is an example of a curricular improvement generated through an assessment process. The resulting educational benefits are very consistent with the University mission and educational philosophy, and with the ABET accreditation requirements. However, the project based laboratory does not eliminate the need to give students hands-on experience with soil behavior concurrent with a lecture class.

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