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Integration of Remote Major Research Instrumentation in Undergraduate Civil Engineering Education

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ABSTRACT

We report the results of a pilot study aimed at developing, implementing, and assessing an educational module that integrates remote major research instrumentation into an undergraduate civil engineering course. Specifically, this study shows the potential of adopting Internet Web-based technologies to allow for real-time video monitoring and execution of cutting-edge experiments in undergraduate geotechnical engineering classes. The students' activities within the module are centered on designing and building a model of a shallow foundation on a sand deposit utilizing a centrifuge facility and using this model for: (1) visual observation of the response of soil-foundation systems, (2) learning the use of instrumentation, (3) interpretation of acquired data, and (4) comparing experimental results to theoretical predictions. Testing a soil-foundation system helped the students identify the lab experiments needed to design the system. A survey was used to gauge the students' learning outcomes as a result of introducing the module. The module proved that remote sites can be made conveniently accessible to students and faculty; thereby, enhancing the learning experience of students that otherwise do not have access to these types of facilities and also help to save educational institutions resources.

INTRODUCTION

There are three types of labs that can be implemented in engineering education: Physical (real) labs; Remote labs; and Simulation (virtual) labs. Simulation labs have been shown to be equivalent to physical labs for explaining and reinforcing concepts (Striegel 2001). Web based

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technologies allow students to work remotely on real equipment and instrumentation located at a distance.

The increasing availability and use of distance education technologies and pedagogies provide opportunities to address the inclusion of remote lab work in engineering education. Remote labs, in which a Web-based technique provides an interface between students and a laboratory, offer access to real equipment. Web-based communication technologies enable students to send commands that then go through a server and execute the experiment on equipment in the real lab. This technique was applied by Marc et al. (2002) to Control and Robotic labs utilizing LABVIEW Web server.

Web-based technologies have been used effectively to demonstrate theoretical concepts using virtual (simulation) experimentation equipment. Internet availability of experimental setups and related computational simulations allow for (1) efficient use of time and resources, (2) flexibility in accessing information, and (3) convenience of self-paced learning with the aid of physical models (Soh and Gupta 2000; Romero and Museros 2002). The interest in developing educational Web sites is increasing rapidly, including: http://flagpole.mit.edu [vibration of instrumented flagpole, Amaratunga and Sudarshan (2002)], virtual experimentation in soil mechanics, Budhu (2002), http://octavia.ce.washington.edu/DrLayer/ [simulation of shear waves in layered media, Arduino et al. (2002)], and http://webshaker.ucsd.edu [Webshaker live shaking table experiment, Elgamal et al. (2005)]. Such a learning environment greatly facilitates deriving physical insight and knowledge, but clearly does not cover the experimental challenges of model construction, instrumentation, and data acquisition.

When compared to actual physical labs, both remote and simulation labs have advantages and disadvantages. Balamuralithara and Woods (2008) summarized key comparison elements between the three types of labs. Physical labs have the advantage of hands-on experience and providing real experiences and practical skills. Access to physical labs, however, is limited and they require costly equipment and large space. Remote and simulation labs share the drawbacks of not promoting support and teamwork as well as developing a feeling for lab safety. The cost of virtual labs is low and access to these labs is not limited.

The pilot study presented herein examines the impact of introducing an Internet-based course module that utilizes major research instrumentation into the regular undergraduate curriculum. Physical modeling and testing has been incorporated in undergraduate geotechnical engineering by a number of researchers and educators (e.g., Craig 1989; Mitchell 1998; Caicedo 2000; Newson et al. 2002). Wartman (2006) argues that a student's understanding and retention of fundamental concepts would be enhanced if physical modeling is strategically integrated into coursework. In geotechnical engineering, reduced scale physical models tested under 1-g environment suffer from the limitation that soil behavior is highly stress-dependent and small scale 1-g models fail to mimic actual field conditions. Geotechnical centrifuge modeling overcomes this shortcoming by subjecting a small scale model to a high gravitational field that produces stress levels in the small scale model similar to those in the prototype. More details about geotechnical centrifuge technology are presented in a companion paper. The experimental learning module is a collaborative effort among three universities; a host institute where the centrifuge facility is located and two remote schools that do not have similar facilities. The goals of the project are to actively engage students in a stimulating and informative educational environment. We aim to provide students with broader insight into advanced research equipment and increase their motivation to learn about geotechnical systems by creating a learning environment that integrates physical modeling into geotechnical engineering education. The educational activities and experiment are intended to enhance students' ability to access, interpret, and evaluate relevant technical information in a timely and effective manner. The expected outcome of the module activities will lead to a better understanding of the physical meaning of engineering principals and improve students' capability to design and conduct experiments.

COURSE MODULE

This pilot study employs Internet Web-based technologies to allow for real-time video monitoring, tele-control, and execution of cutting-edge experiments utilizing a research-oriented centrifuge facility at a remote institution. Engaging research experimentation in the typical geotechnical engineering classrooms provides undergraduate students with broader insight into advanced research equipment and motivates them by creating a new learning environment. The goals of this study are: (1) to build, organize and test an online module for students across different campuses; (2) to test the viability of remote lab assignments taking advantage of advanced telecommunication technology; (3) to introduce a unique physical modeling experimentation environment and make it conveniently accessible to students, faculty and other learners; and (4) to save instructors and educational institutions resources in terms of time, effort, and lab-space by providing Web-based, sharable lab resources.

The students’ activities within the developed module were centered around building a model of a shallow foundation on a sand deposit utilizing the centrifuge facility and using this model for: (1) visual observation of the response of soil and soil-foundation systems, (2) learning the use of instrumentation, (3) interpretation of acquired data, and (4) comparing the experimental results to theoretical predictions. Specifically, a centrifuge experiment was introduced in undergraduate courses to examine the performance of a shallow footing constructed on a deposit made of dry sand. The following learning outcomes were set for the module. As a result of participating in the module/lab, students will be able to:

a) better understand current principles of geotechnical and foundation engineering by experiencing the actual response of soils and soil-foundation systems;
b) design experiments using advanced procedures, instrumentation and applications; and
c) monitor, evaluate, analyze and design soil and soil-foundation systems using appropriate instrumentation, electronic data collection and state-of-the-art geotechnical engineering workplace applications and technologies.

The experiment was conducted in the Spring semester of 2012 and for the most part included primarily undergraduate civil engineering students at three campuses. However, the entire class at one of the remote institutions was composed entirely of three graduate students. All participating students had taken at least one introductory course on geotechnical engineering prior to that semester and were familiar with topics such as phase relationships, compaction, permeability and seepage, effective stress and stress distribution, shear strength of soils, and bearing capacity of shallow foundations as well as the traditional geotechnical lab experiments.

The instructors at the three institutions collaborated in planning the learning activities for the project. The instructors faced a number of logistical challenges associated with synchronizing the project tasks at the three schools. To accommodate for different course schedules and start/end dates, students were informed at the start of each course that the project would require that they attend one late afternoon during a specified week. Students at the remote sites were given the opportunity to contact students at the host institution for technical help. All students, regardless of the school they attended, viewed the experiment remotely. A lecture covering centrifuge concepts and scaling laws along with sample implementations was presented prior to the start of the project activities. The lecture was held live for the host institution students and was streamed in real-time over the Internet to the remote students. The module was a term project composed of two assignments. The first assignment was given to the students about five weeks before running the centrifuge experiment and included three tasks. In Task 1, students were asked to sketch the location of tactile pressure sensors that could be placed under a shallow footing to predict the stress distribution inside the soil mass. Students were also asked to identify the soil parameters needed to evaluate soil strength and the experimental lab experiments needed for that. In Task 2, students were asked to predict the maximum column load that could be placed if the soil is known to be Nevada sand with a specified relative density (shear parameters were not given). In Task 3, students were asked to design the centrifuge model of the footing and the soil deposit assuming the test would run under a gravitational field of 25 g which would include a scaled dimension of the footing and the deposit as well as the location of pressure sensors under the footing, all in model units. The solutions to this assignment were due in 10 days from the day the assignment was given to the students.

The first assignment contained the following pre-experiment activities:

1. Gather information about centrifuge technology and associated scaling laws relevant to the problem under consideration,
2. Review information pertaining to safety precautions and procedures involved in centrifuge modeling. These include safety of the personnel and ensuring that the designed experiment will not damage the utilized equipment, and
3. Design the model of the test (define dimensions and materials) and specify what needs to be measured as well as the type and proper locations of sensors for the application.

Discussion of students' solutions took place in each school and students were shown the final design of the model (Fig. 1). Students at the host institution then built the physical model based on that design. Students on the remote campuses were kept updated of the model progress and one of the remote schools students engaged in building a dummy model to learn how the soil deposit is created and how sensors are installed. The actual centrifuge experiment was conducted on April 2, 2012. To resolve scheduling issues, the host institution students observed the experiment on the morning of April 2 and another experiment was performed in the late afternoon of that day for the two remote schools students. WebEx and specialized telecommunication tools were used so that students at the remote sites could observe the live experiment from different camera angles.

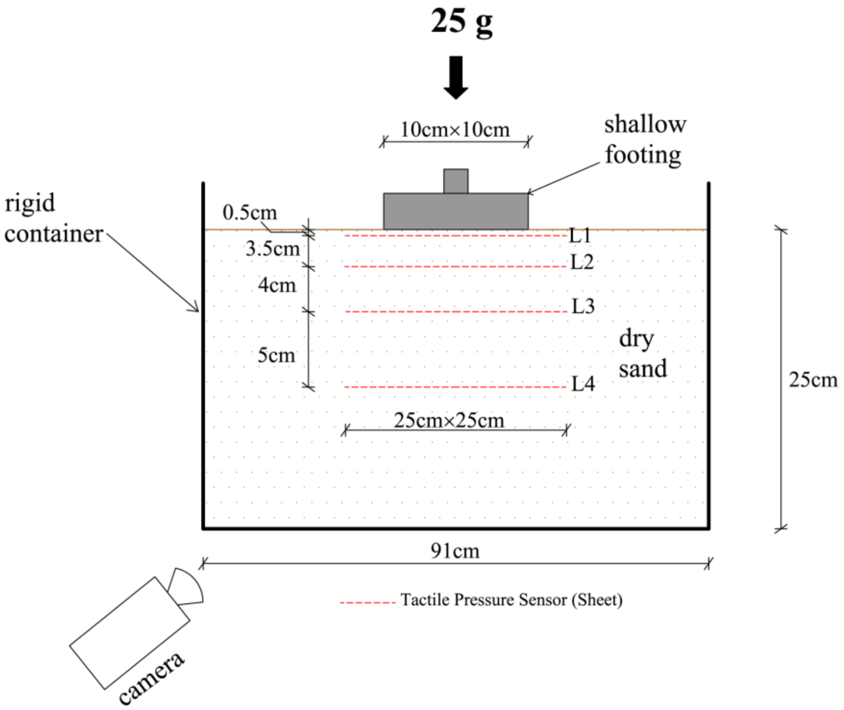

Figure 1. Layout of the final design of the centrifuge model subjected to a centrifugal gravitational field of 25 g (not to scale).

The experiment consisted of two tests. In the first test, the model footing was positioned in the middle of the container (Fig. 2) and loaded by means of an in-flight robot. The stresses on the four tactile pressure sensors shown in Fig. 1 were monitored in real-time and students were able to see the anticipated stress distribution with depth (Fig. 3). The second test was carried out to evaluate the ultimate bearing capacity of the footing and visualize the development of the failure surface. For this purpose, the footing was relocated near the edge of the container where the side is made of transparent acrylic and the sand deposit was colored in layers to help visualize and track the deformation of the underlying soil. The footing was loaded incrementally to failure and students were able to see, in real-time, the shape of the load-displacement curve and the development of failure wedges underneath the footing (Fig. 4).

Following the completion of the experiment, the recorded data were made available to all students and they were handed the second assignment on April 5. This assignment included the following activities:

1. Predicting the performance of the foundation. That is, predicting the stress distribution at different levels beneath the footing and estimating the bearing capacity of the footing. Included in this task obtaining the physical and mechanical properties of the tested sand,
2. Running the experiment, using the tele-presence facility, under the supervision of the Instructors,
3. Analyzing the test results and producing relevant plots, and
4. Comparing the results from the centrifuge test to that obtained from theoretical calculations employing data from elementary geotechnical testing (e.g., direct shear and triaxial tests).

In Assignment 2, the students were asked to compute the theoretical stress distribution and compare it to the experimental data. They were also asked to predict the bearing capacity of the footing and compare it to the experimental results. In doing so, students must first convert all data to prototype units. Students were also asked to comment on the results and discuss the potential sources of differences, if any. This second assignment was due two weeks from the day it was handed to the students. Upon receiving the solutions from the students, they were asked to complete a survey designed to assess the outcomes of the module.

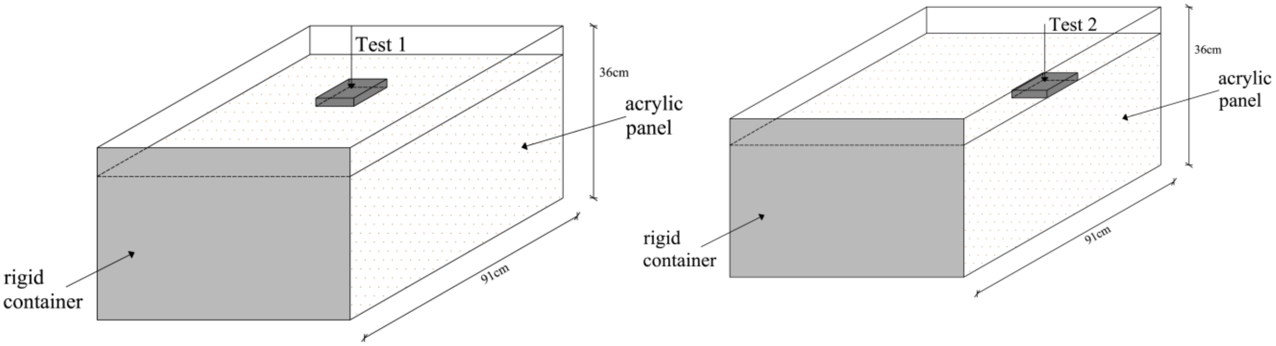

Figure 2. Layout of centrifuge model tests 1 and 2 (not to scale).

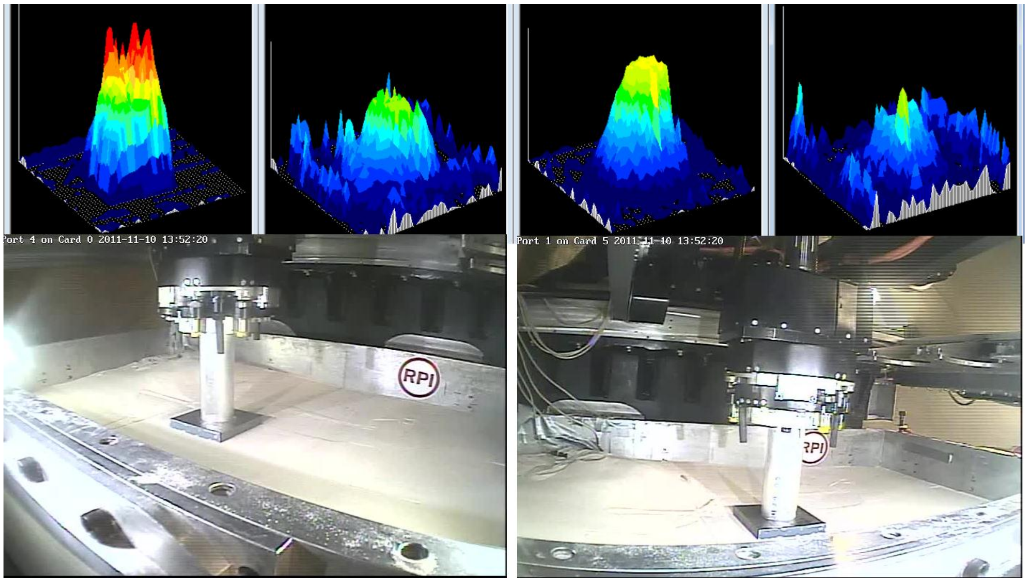

Figure 3. A screenshot from Test 1 obtained from the live streaming the remote students observed while running the experiment.

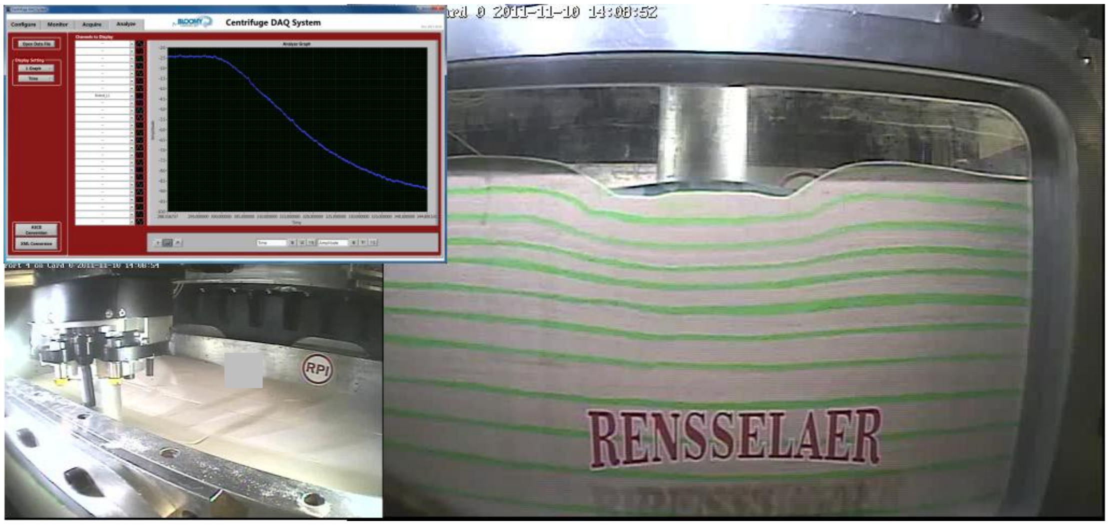

Figure 4. A screenshot obtained from Test 2 while running the remote experiment showing soil deformation under the footing and soil heave near the surface.

ASSESSMENT

The paper focuses on the initial implementation of the online centrifuge experiment. The premise of the project is that student learning of geotechnical engineering concepts will by enhanced or improved through their participation in the centrifuge experiment. In this pilot project, no comparative data were available given that the concepts covered by the experiment had not been taught in prior versions of the courses. The focus of the pilot project was to determine how to most effectively run a remote lab such as this and to gain insight into student learning based on student self-reports regarding their learning and their reflections on the assignments and technology. The survey also covered students' prior experience with experimentation (online and in person), their opinions regarding the experiment and associated assignments, the quality and 'user friendliness' of the online experiment, and their opinions regarding the impact of the experiment on their learning. All opinion questions were designed using a five point Likert scale from 'Strongly Disagree' to 'Strongly Agree'.

Survey Results

Forty-four students representing all of the schools completed the survey; a paper version of the survey instrument was used with students at one of the remote schools; students at the other schools completed the online version of the survey instrument. The response rate was 100%. Twenty-three percent of the students were graduate students; 77% undergraduates (seniors and juniors). As the focus of this presentation is on undergraduate engineering education, only the response of the undergraduate students is reported.

Students were asked to rate their confidence in designing and running experiments in general. Only 56% of the undergraduates reported that they were confident with a large portion (44%) reporting they were 'Neutral' or less than 'Confident'. These response patterns were also consistent when comparing responses by school. Students were asked to describe their general opinion about the experiment and associated assignments. Overall, students felt they were 'just about right' (see Table 1). Students were also asked to rate the helpfulness of specific pre-experiment activities and assignments. In general, students felt that the pre-experiment activities were quite useful in preparing them to conduct the experiment with almost 60% agreeing or strongly agreeing to the prompt (Table 2). Students rated the activities lower with regards to preparing them to analyze the results of experiment. Only around 50% selected 'Agree' or 'Strongly Agree' that the in-class or remote lectures and discussions helped to prepare them (Table 2).

Table 1. Undergraduate Students General Opinion about the Centrifuge Experiment and Associated Assignments

1 Too challenging	2 Just about right	3 Somewhat easy	4 Too simple	Mean
11.0%	82.3%	5.9%	0	1.93

Table 2. Percentage and Mean Ratings of the Level of Preparation Provided by Pre-Experiment Activities

Regarding the assignments and classes prior to conducting the centrifuge experiment:	Strongly Disagree 1	Disagree 2	Neutral 3	Agree 4	Strongly Agree 5	Mean
the in class lectures and discussion prepared me for conducting the experiment	0	20.6%	23.5%	50.0%	5.9%	3.4
the remote lecture(s) and discussions(s) prepared me for conducting the experiment	0	3.0%	30.3%	48.5%	18.2%	3.8
the in-class lectures and discussions prepared me for analyzing the results of the experiment.	0	17.6%	35.3%	35.3%	11.8%	3.4
the remote lecture(s) and discussion(s) prepared me for analyzing the results of the experiment.	0	6.1%	36.4%	45.5%	12.1%	3.6

Students' responses to the open-ended question about the kinds of problems they encountered in interpreting the results of the experiment lend some insight into this result. Responses indicated several types of problems, including: unclear assignment, that the data returned were confusing (in display and because they were unfamiliar with this type of data) and that they had problems with specific concepts such as determining strain or the failure criteria.

To learn about the impact of the experiment on student learning, students responded to a series of questions regarding how the experiment affected their learning. Since none of the courses had included this experiment previously, student self-reports on their own learning served as a proxy for other measures such as test or assignment grades. Table 3 describes the responses to the four questions associated with what students learned. Explorations of the data by type of student (graduate or undergraduate) or institution did not reveal large differences; Table 3 describes the findings for all responses. Overall, students found the experiment to be a very effective way to learn concepts about stress, and load bearing capacities associated with different foundations. Students also agreed that the experiment helped them visualize and better link field conditions, experiments and physical modeling.

Table 3. Percentage and Mean Ratings of the Effectiveness of the Centrifuge Experiment in Learning Geotechnical Concepts

The centrifuge experiment was an effective way:	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree	Mean
to learn about the actual stress distribution under a loaded foundation	0	2.9%	0.	29.4%	67.6%	4.6
to learn about the actual bearing capacity of a shallow foundation	0	2.9%	2.9%	41.2%	52.9%	4.4
to visualize the failure mechanism under a shallow foundation	0	2.9%	8.8%	35.3%	52.9%	4.4
to link field conditions, traditional lab experiments and centrifuge physical modeling	0	0	9.1%	30.3%	57.6%	4.5

One of the goals of this project was to learn what works and does not work in terms of adapting or adopting live, remote experiments in a class or course. To determine the ‘workability’ of the experiment, students rated a series of questions that related specifically to the experience of watching the experiment (Table 4). The high ratings indicate the importance of being able to view the experiment (not just read about it) and that the quality of the images and experience of watching the experiment real time was not an impediment to the experience. Questions were also asked to determine students’ interest in various aspects of the experiment such as, the use of technology, collaboration with other students at their own campus or with students from other campuses and their desire to be more involved in building or testing their own models. In this case, students tended to strongly agree on almost all aspects of the experience (Table 5).

Table 4. Percentage and Mean Ratings of the Quality of the Remote Experiment

Rate the following aspects of the centrifuge experiment.	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly Agree	Mean
Being able to view the live centrifuge was important to the experiment.	0	2.9%	5.9%	44.1%	47.1%	4.3
The image of the centrifuge was clear.	3.0%	3.0%	6.1%	51.5%	36.4%	4.2
The live demonstration was too long to view.	17.6%	55.9%	17.6%	8.8%	0	2.2

Table 5. Students' Response Regarding Use of Online, Remote Experimentation

After conducting the centrifuge experiment:	Undergraduate Mean
I would like to conduct more experiments using this technology.	4.1
I would like to conduct more experiments like this working online by myself.	3.2
I would like to conduct more experiments like this working online with only students from my school.	3.6
I would like to conduct more experiments like this working online with students from other schools.	3.6
I would like to experiment with building the physical model that is tested.	4.3
I would like to have more online sessions that include students from the other schools who are also working on the assignment.	4.0

Scale: 1 = strongly disagree; 5 = strongly agree

To confirm students' opinions regarding the experiment, they were asked if they would recommend it to their friends or colleagues. Ninety eight percent of the students said they would do so, noting in their comments that they thought it was interesting and enjoyable, that they learned a lot because it was new material that was not included in previous courses, or that access to the centrifuge made it possible. A number of students commented about the real world nature of the experience and how practical it was. The main reasons they wouldn't recommend it was because their friends or colleagues were not involved in geotechnical engineering. Example responses included:

I think the experiment helped me apply what I learned from my assignments to a real life situation. It was challenging but we were well prepared.

I find the subject interesting and I enjoyed being able to watch the experiment live. It was very helpful to actually be able to watch the experiment as opposed to just reading about it.

I thought the experiment was very useful to actually see a lab test being performed that could possibly be used in future design considerations. Anyone can look up equations or theory in a textbook or on the internet, but actually getting to see how those relate to real world situations is very useful and for me, it helped me understand certain concepts better.

I really enjoyed the project, it was time consuming but worth it, and I used resources (office hours) which helped a lot.

I think it was an interesting project but very challenging

The principles of the centrifuge tests were fairly easy. However, the assignments provided enough challenge for students to analyze and make deeper conclusions about experiment results.

Discussion of Results and Implications

The results from the survey indicate that students found the experiment to be interesting, challenging and worth their time and effort. The faculty members involved in the remote sites indicated that they felt the experiment required their students to ‘go an extra mile’ to understand how to complete the assignment, something that they had not been accustomed to. Student comments reinforced this observation, adding that they felt the effort was worth it. The survey also showed that students felt they had accomplished the learning goals for the course, e.g., learning about actual stress distribution under a loaded foundation. To further explore the actual learning and move the project beyond this pilot stage, these results might be compared to grades on the assignment to determine the level of learning of these concepts. Furthermore, students might be queried later in their academic careers about the impact of learning these geotechnical concepts for other classes, graduate school or jobs.

CONCLUSIONS

The installation of an educational module that for the first time integrates remote major research instrumentation into an undergraduate class appears to have been successful. Students’ perceptions of the module were very positive. Students agreed that observing the stress distribution under the footing and loading it to failure in the live experiment helped them better understand stress distribution and bearing capacity. Additionally, many students showed interest in interacting with students from other schools. Many students showed interest in seeing more experiments like this one for other applications in geotechnical engineering.

The implemented course module aided in enhancing students’ understanding of geotechnical systems and the link between elementary soil testing and system design. Testing a soil-foundation system helped the students identify the lab experiments needed to design the system. Students were able to acquire actual system test data that are similar to field data and use it to compare with the outcome of using theoretical analysis that is based on element testing. Such a comparison stimulates critical thinking to identify the approximations in the theory and/or the setting of the experiment that may lead to differences between computed values and measured data. The module introduced a unique physical modeling environment and our results indicate that such remote facilities can be made conveniently accessible to students and faculty; thereby helping in saving educational institution resources.

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