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Multi-Institutional Physical Modeling Learning Environment for Geotechnical Engineering Education

Dr. Tarek Abdoun, Rensselaer Polytechnic Institute

Professor Dr. Tarek Abdoun is the Iovino Chair professor and associate dean of Research for the School of Engineering at Rensselaer Polytechnic Institute (RPI). He is the technical director of NSF Network for Earthquake Engineering Simulation (NEES) Facility at RPI.

Dr. Usama El Shamy P.E., Southern Methodist University
Dr. Anthony Tessari
Victoria Bennett, Rensselaer Polytechnic Institute
Mr. John E Lawler, Rensselaer Polytechnic Institute

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Abstract

This paper discusses the preparation and pre-evaluation for the development and implementation of an educational module that integrates major remote research facilities into undergraduate classes. The developed educational module incorporates state-of-the-art experimental tools (geotechnical centrifuge) into the undergraduate education curriculum via web-based technologies that enable real-time video monitoring, tele-control, and shared execution of experiments. The students' activities within the developed module are centered around building a model consisting of a shallow foundation on a sand deposit utilizing the Network for Earthquake Engineering Simulation (NEES) centrifuge facility. The project provides students at three different engineering universities with new educational tools for improving their understanding of various geotechnical engineering concepts. The main goals of this project are: to develop and pilot test educational models utilizing the centrifuge facility at one of these universities; to provide visual observation of the response of soil and soil-foundation systems; and to promote student-based use of instrumentation, interpretation of acquired data, and utilization of the NEES 3D data viewer in order to analyze the measured response. Students were able to access, interpret, evaluate, and exchange relevant technical information via the Internet thereby bringing major experimentation into geotechnical engineering classes.

In order to ensure successful development and implementation of the multi-institute educational model, a preliminary implementation was conducted in the fall of 2011 at two of the three universities. Students at one university involved in this trial were undergraduate research students, while those participating at the second one did so as part of a soil mechanics and foundations class. The close interaction with undergraduate research students helped in identifying potential problems at early stages and allowed for timely corrections as the second university's class progressed. This paper presents the results and lessons learned through early implementation. It focuses on explaining centrifuge technology, the tools used to build the model, testing logistics, and methods adopted to resolve obstacles encountered during execution of the module. The student survey indicates that the developed module successfully addresses an important educational gap - students' lack of understanding of the strong relationship between soil laboratory testing, system design, and field performance. The survey also highlighted the fact that students did appreciate the practical nature of the project. The educational module was revised and successfully implemented in the spring of 2012 at the three universities.

Introduction

The undergraduate engineering curriculum is frequently supplemented with hands-on laboratory-based experimentation. This has been shown to clarify, support, and reinforce material covered during lectures. Recent studies have indicated that students receive similar benefits when participating remotely via communication technologies[9]. It has also been suggested that fundamental understanding and retention would be enhanced if physical modeling were incorporated into classwork[11]. As undergraduate education continues to grow with regards to depth, range, and scope, an opportunity arises to prepare an experimental complement that will address additional modern issues.

The widespread adoption of information technology in industry has allowed geographically separated groups and individuals to collaborate on multi-faceted projects. Researchers have also shown that the same web based technologies and real-time interaction is possible for a remote classroom[2,6]. Incorporating a similar experience into undergraduate education introduces the students to remote teamwork while simultaneously reinforcing course material. The challenge lies in developing an experimental module that will engage students and facilitate remote collaboration. A study performed by Balamuralithara and Woods[1] investigated the differences and similarities between physical and virtual labs. They found that physical labs have the advantage of providing hands on experience and practical skills. Remote or virtual labs had the drawback of not promoting teamwork or other tangible skills, such as lab safety. Therefore, one of the goals of this learning module is to address the deficiencies experienced by remote users.

Major experimental equipment is infrequently used as a teaching device in the undergraduate curriculum. This is primarily due to the economics and time constraints involved in their operation. However, real-time remote participation of several educational institutions changes this paradigm. The following study examines the challenges and logistics of incorporating major experimental equipment into the undergraduate classroom. The geotechnical centrifuge at Rensselaer Polytechnic Institute (RPI) is utilized for the physical testing and the experiments are designed, analyzed, and constructed by the consortium of undergraduate students at both RPI and Southern Methodist University (SMU).

Geotechnical Centrifuge

Researchers have discussed the merits of using small instructional centrifuges for education and note that they can be effectively used to demonstrate core concepts relating to slope stability, foundation interaction, tunnel stability, piles, retaining structures, and lateral pressure thoery[3,4,7]. The use of a research-grade geotechnical centrifuge for this module delivers all the benefits associated with large-scale physical modeling while still maintaining the monetary and time advantages of reduced size testing. Figure 1 illustrates the concept of centrifuge modeling. The centrifuge produces stress conditions in a model that mimic field equivalents via an increased gravity level. The artificial increase in the gravity field produces a real world stress profile in a small-scale model[10]. This enables economical and time efficient parametric testing of field installations that would otherwise be physically or financially impractical.

Experimental Module

The preliminary trials were designed in order to meet several objectives, which are: to develop and pilot test educational models utilizing the centrifuge facility; to provide visual observation of the response of soil and soil-foundation systems; and to promote student-based use of instrumentation, interpretation of acquired data, and utilization of the NEES 3D data viewer in order to analyze the measured response. The students at two universities were divided into groups and collaborated using various communication technologies. There were 14 combined undergraduate participants in the pilot program. The students at the remote university were participating as part of a soil mechanics class and had previously taken courses covering statics and mechanics of materials. As will be discussed later, the host students were varied in their respective levels of education. Their goals during the project were:

1) to develop an understanding of centrifuge technology and its use in discovering the concepts and principles of geotechnical engineering.
2) to learn the methods and devices used to construct models in addition to the logistics of testing.
3) to use a variety of resources in order to interpret and analyze the experimental results.

The project was split into several segments in order to account for the time differences and course schedules at the different schools. The instructors guided their local students until the point at which they were put into groups. The project was divided into two main tasks, which were performed collaboratively between the group members but submitted individually. Students at the host institution were given extensive equipment and safety training. They were provided the opportunity to interact with and obtain data from the instrumentation. Students at the remote university were instructed to communicate with the host school students in order to obtain information vital to conceptual understanding of the assignments. The first portion of the project was assigned to the students before running the experiment. This was divided into three subtasks which asked the students to design the instrumentation plan for a shallow footing in order to obtain the stress distribution in the soil medium, calculate the maximum vertical load of a square footing over a known soil, and finally to scale the previous results for a test that would be performed at 25g (Figure 2). The students were given limit values for the instrumentation, which included tactile pressure sensors and traditional load cells. The tactile pressure sensors, as shown in Figures 3 and 4, are capable of producing a 2-dimensional stress picture. If placed horizontally within the soil, they will generate the stresses produced at that particular plane. The assignment hinged on finding a solution for the width of the foundation that accounted for the stress limits and physical size of the tactile sensors and the force limit of the actuator's load cell.

The assignments were collected and the solutions were statistically analyzed in order to find the average values for the instrumentation plan and footing size. The instructors discussed the results and presented the final model based on the mean solution. With the geometry decided, as depicted in Figure 5, the host students constructed the model. Figure 6 shows several steps in this process, which include placing of the sand soil layers and insertion of the instrumentation. The model was loaded onto the centrifuge and the sensors and instrumentation were connected. The footing was connected to a state-of-the-art robot, which performed the loading.

The experiment was conducted in a time slot where both the local and remote students were available. This corresponded with a class session for the remote university. The instructors and students connected via WebEx and a presentation of the material and what to watch for in the ensuing experiment was given. The centrifuge facility installed several cameras in the laboratory and on the centrifuge platform itself. These feeds were viewable in the local control room (Figure 7) and broadcast online. Therefore, both groups of students were able to view the experiment through the same lenses.

The experiment was split into two trials that corresponded to the two tasks in the first assignment. While the centrifuge was spinning at 25g, the robot positioned the square footing over the center of the container and began loading the soil mass containing the tactile pressure sensors. The data was observed live in both 2D and 3D representations as depicted in Figure 8. The data was recorded and disseminated as part of a data package following the experiment. Once the sensors were saturated in terms of readable pressure, the second portion of the experiment was performed. The robot moved the square footing to the boundary of the model container. The boundary, in this particular instance, is composed of a transparent material. The footing was pushed into the soil mass until failure developed. The model was constructed with horizontal lines comprised of green sand at 2 cm increments along the transparent boundary. As the soil failed, the colored bands highlighted shear lines as shown in Figure 9. The load cell from the robot actuator was monitored and its readings were recorded during this process.

The students were provided with all the data acquired during the experiment in raw model units. They were given the second part of the project, which asked them to analyze the results generated during the experiment and compare them to their initial predictions. Using the tactile pressure sensors, they derived the actual stress distribution in the soil mass and compared that to theory. The data from the foundation push was used to produce the bearing capacity of the system. The students then compared this value to the one they computed in the first assignment. They needed to draw upon centrifuge modeling concepts in order to properly scale the data to field units.

Pilot Testing Advantages

The students at the host school participated as part of an undergraduate research program. They were assigned to the project for the semester and were part of an early preliminary version of the module. The main advantage to this approach was that potential problems, both information and logistics based, were addressed before the remote undergraduate class students were involved. Approximately two weeks prior to an actual task, the host students would be given the opportunity to run through an initial trial. There were six students involved in this operation, which ensured that several opinions and experiences would be documented. The group contained three students that had already taken a class with a similar syllabus and three students that were currently enrolled in a comparable course. This created an environment where some of the students knew what to expect and could catch potential sources of error. Furthermore, the currently enrolled students were able to identify areas where misinterpretation would occur and where clarification was needed.

During the pre-testing by the host students, they identified and assisted in correcting several potential issues. Starting with the first assignment, the new students were unfamiliar with some of the standards used in the figures. They projected planar information incorrectly and the assignment was modified to account for this concern. The experienced students were asked to read the problem statements and find sources of possible misinterpretation. Their input led to a better formulation of the assignment, which resulted in fewer questions from the remote students. The experience was beneficial to the instructor, who was able to anticipate and prepare answers for typical questions.

The physical testing was also performed prior to the collaborative experiment in order to diagnose problems. The host students encountered a few issues during construction of the model and these were corrected before the actual trial. The dry run was also beneficial in preparing for the actual experiment. Since the test would be broadcast live in a small time window, all procedures and configurations were established to minimize delays. The students' reaction to the initial data was positive and they suggested ways to display the information that was intuitive to their understanding.

Student Response

The participating students, both in the host and remote universities, were asked to evaluate the module via a survey. The overall response of the students was favorable and they indicated that they found the experience to be valuable. Table 1 contains the percentage and mean results from the survey given to the remote undergraduate students. Written responses from students included comments regarding the real world aspects of the project as it pertains to large-scale geotechnical engineering, the engaging aspects of participating actively and in real-time as opposed to passive presentation, and the relationship between theoretical, empirical, and experimentally derived data. Over 90% of the combined students had a favorable response of the centrifuge experiment and the practical experience gained from both assignments. They indicated that the assignments encouraged them to think critically and make deeper conclusions about the experiment results than they would have otherwise done with a regular classroom-based exercise.

The main detraction from the experiment, according to the students, was the amount of work required to complete the assignments. The undergraduate students enrolled in the course indicated that it required an increase in the amount of time required for a typical class. Similarly, the undergraduate researchers involved at the host institution commented on the additional workload. Both student groups suggested that the centrifuge project should be kept unchanged and that some other traditional lab experiments, which could be covered in other courses, could be eliminated to reduce the overall time necessary to complete course assignments and lab reports. Future iterations of the model will incorporate student recommendations of reducing traditional laboratory-based experimentation reports or permitting class students to submit deliverables as a team.

Conclusions

The use of large-scale experimentation to support undergraduate geotechnical engineering education has been implemented at two institutions and shows promise for integrating several more in the future. The virtual laboratory environment coupled with the geographically diverse student teams facilitates remote collaboration in an ever increasingly globalized world. The developed and pilot-tested education module has been verified by the student participants. It enhances the undergraduate classroom curriculum by tying in cutting-edge experimental tools and actively verifying core concepts that are typically presented in a passive manner. The students were able to participate in a dynamic design process, which necessitated a multi-faceted solution. The synergistic approach to design and testing resulted in a deeper understanding of the material, as stated by the students. Furthermore, the students were given access to analysis and visualization tools, which enhanced their ability to internalize the results. The pretesting by the undergraduate researchers at the host institution mitigated potential sources of error and misinterpretation. The proactive approach of using a small but diverse group of students in preliminary testing ensured that the module was successful during the actual trial. The size of the host student group was large enough to generate a variety of insightful comments and suggestions. However, it was small enough that the instructor was able to devote the necessary time resources to each student. Furthermore, the differences in the education of the students involved allowed the instructor to evaluate the assignments and project from several perspectives. Additional information can be found at the centrifuge facility website (http://nees.rpi.edu).

References

1. Balamuralithara, B. and Woods, P.C. (2008). Virtual Laboratories in Engineering Education: The Simulation Lab and Remote Lab, *Computer Applications in Engineering Education*, 17, pp. 108-118.
2. Budhu, M. (2002). Virtual laboratories for engineering education, In *International Conference on Engineering Education*, Manchester, UK.
3. Caicedo, B. (2000). Geotechnical centrifuge applications to foundation engineering teaching, *In 1st International Conference on Geotechnical Engineering Education and Training*, Balkema, Rotterdam, pp. 271–274.
4. Craig, W. H. (1989). Use of a centrifuge in geotechnical engineering education, *Geotechnical Testing Journal*, 12(4), pp. 288–291.
5. Elgamal, A., Fraser, M., and McMartin, F. (2005). On-line educational shake table experiments, *Journal of Professional Issues in Engineering Education and Practice*, 131 (1), pp. 41-49.
6. Marc, S., Stefan, Z., Thomas, J., and Torsten, B. (2002). Global architecture and partial prototype implementation or enhanced remote courses, *Computers and Advanced Technology in Education*, Cancun, Mexico.
7. Newson, T. A., Bransby, M. F., and Kainourgiaki, G. (2002). The use of small centrifuges for geotechnical education, In *International Conference of Physical Modeling in Geotechnics*, St. Johns, Canada, pp. 215–220.
8. Romero, M. L. and Museros, P. (2002). Structural analysis education through model experiments and computer simulation, *Journal of Professional Issues in Engineering Education and Practice*, 128(4), pp. 170-175.
9. Striegel, A. (2001). Distance education and its impact on computer engineering laboratories. In *Frontiers in Education Conference*, 2, pp. F2D-4.
10. Taylor, R. (1994). *Geotechnical centrifuge technology*, Chapman and Hall, London.
11. Wartman, J. (2006). "Geotechnical physical modeling for education: learning theory approach," Journal of Professional Issues in Engineering Education and Practice, 132(4), pp. 288-296.

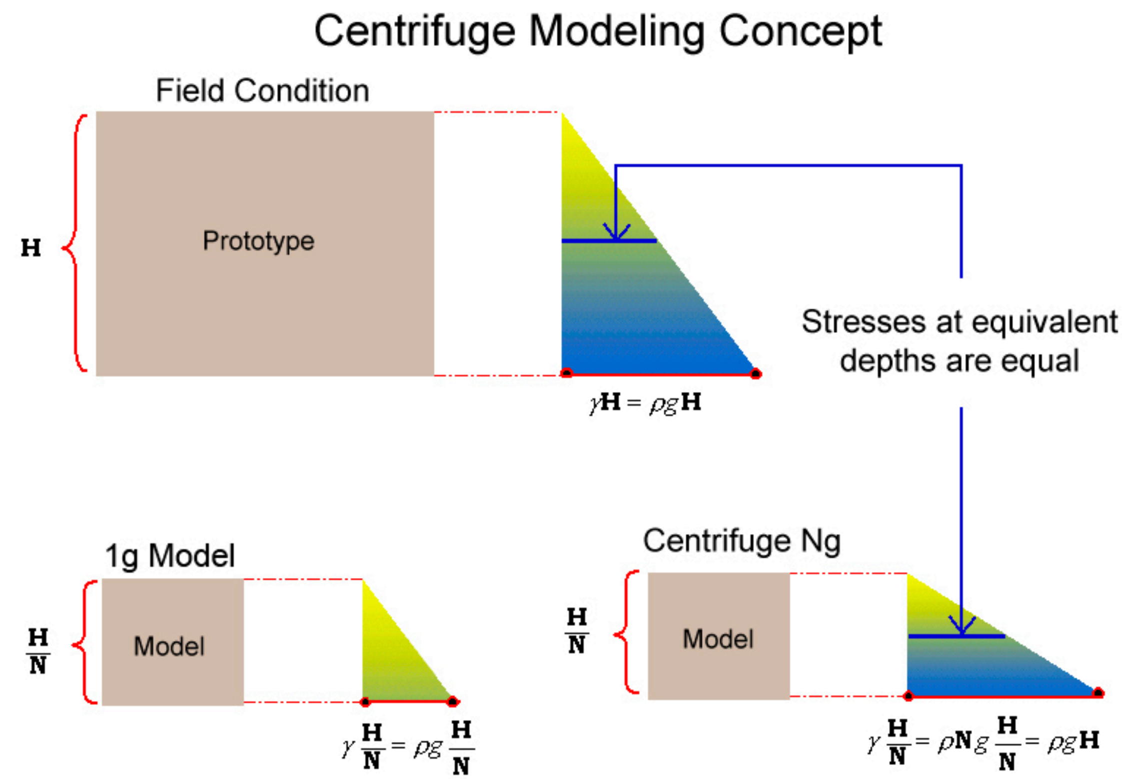

Figure 1: Concept of centrifuge modeling

Figure 2: Undergraduate students discussing the experimental plan in teleconference room

Figure 3: Tactile pressure sensor system

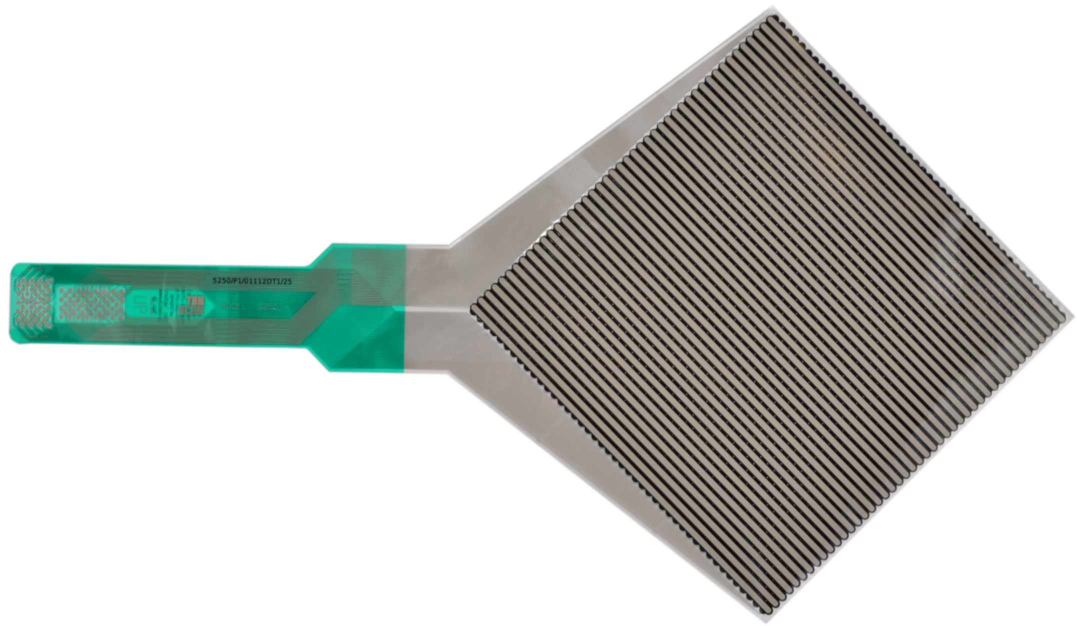

Figure 4: Tactile sensor utilized in testing

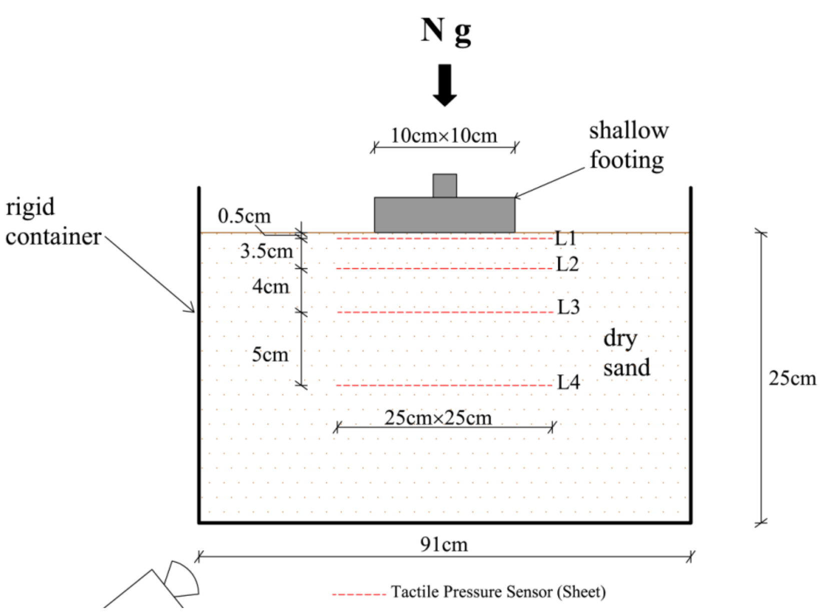

Figure 5: Tactile sensor testing setup

Figure 6: Undergraduate students preparing model soil and instrumentation

Figure 7: Undergraduate students participate in trial run in telecontrol room

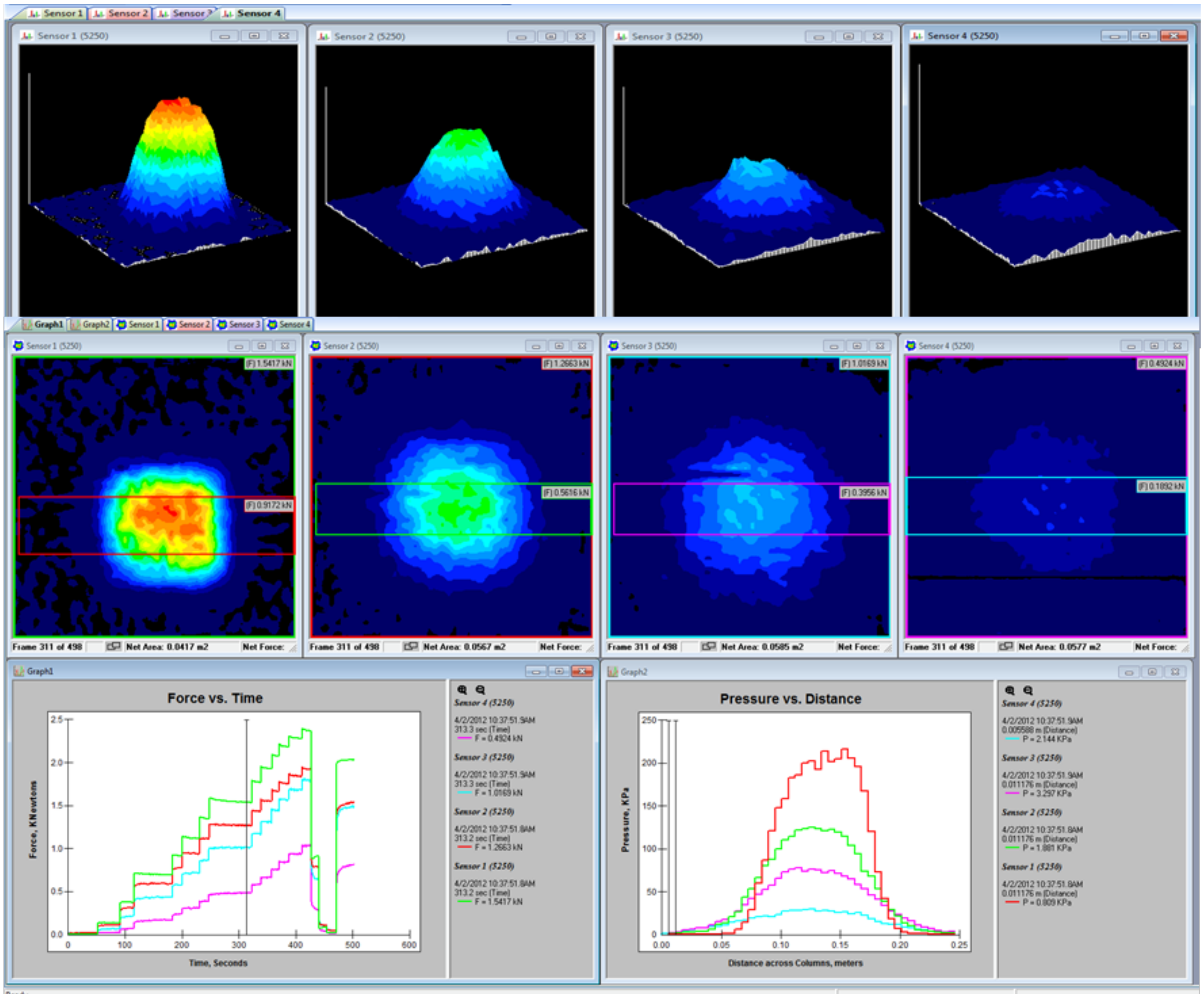

Figure 8: Data from tactile pressure sensors in both 3D (top row) and 2D (middle row)

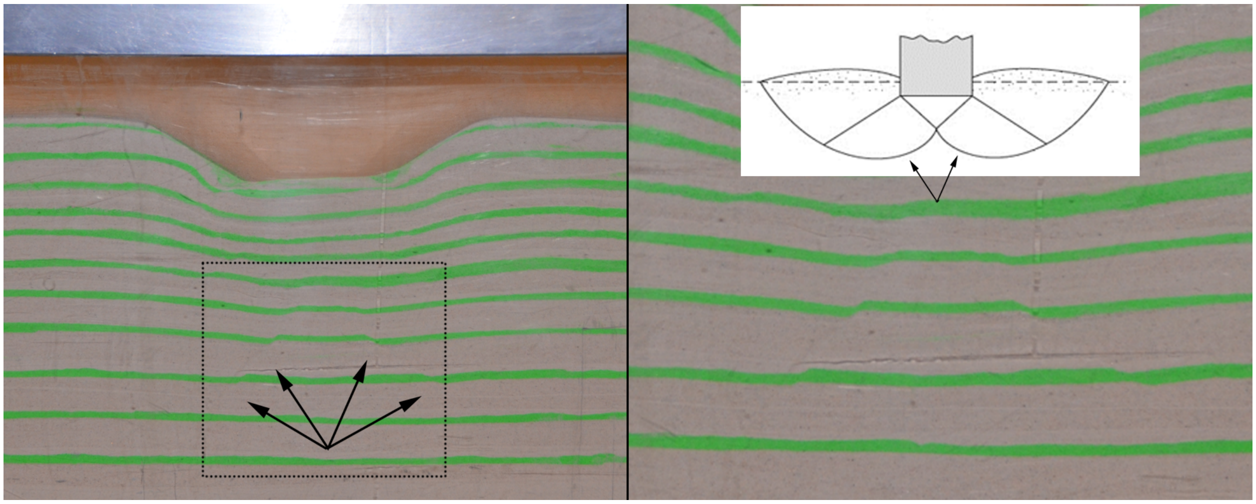

Figure 9: Bearing capacity failure from foundation push at transparent boundary

Table 1: Percentage and mean ratings of the effectiveness of the collaborative experiment in learning geotechnical concepts

The experiment was an effective way to:	1 Strongly Disagree	2 Disagree	3 Neutral	4 Agree	5 Strongly agree	Mean
Learn about the actual stress distribution under a loaded foundation	0	0%	0%	37.5%	62.5%	4.6
Learn about the actual bearing capacity of a shallow foundation	0	0%	0%	50%	50%	4.5
Visualize the failure mechanism under a shallow foundation	0	0%	12.5%	25%	62.5%	4.5
Link field conditions, traditional lab experiments and centrifuge physical modeling	0	0	0%	37.5%	62.5%	4.6