Effective Stress and Upward Seepage Laboratory Demonstration

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Abstract

Understanding the different ways students grasp information, specifically students in STEM related fields, is necessary for effective teaching. The two main approaches for learning/teaching are the inductive and deductive approaches. There is an obvious conflict in the classroom regarding the way students learn and the method of teaching used by professors. Implementing both inductive and deductive teaching methods by the use of hands-on lab work or by the use of simulated demonstrations within the course can increase the effectiveness of teaching. These fundamentals are directly related to real world engineering projects in the field and how students can build the connection between concept and application.

One of the most important aspects of geotechnical engineering is understanding the behavior of soils under different conditions. A senior design team has been advised to design and build a laboratory demonstration to accompany corresponding lectures in introductory soil mechanics courses aimed at studying the effects of upward seepage and the reduction of effective stresses during the process of liquefaction in soil, more commonly known as quicksand. This area of study was chosen for the dual purpose of providing laboratory time for college students enabling them to observe and connecting with real-world project failure mechanism study as well as provide simple, yet effective, displays for K-12 outreach events. It is the goal of the advised senior design team to help connect, inspire and greatly impact the geotechnical learning that takes place on campus by opening opportunities for further more in-depth research studies.

Introduction

Understanding the different ways in which students, specifically those in a STEM (Science Technology Engineering and Math) related field, learn and comprehend material at universities across the country is crucial for effective teaching. Two main approaches to teaching and learning alike are the inductive and deductive approaches. The inductive approach begins with making observations and taking measurements for analysis and then arriving at the laws and theories that explains why you saw what you saw. This is the natural learning style for students. The deductive approach begins with the laws and theories leading to applications and is the natural way for professors to teach the material. It is obvious there is a conflict of interest between professors and students, which can act as a barrier for effective learning and is most prevalent in engineering based courses [1].

Engineering problems studied and taught in a classroom usually requires an individual to make assumptions or only consider ideal design conditions throughout the problem in order to simplify important concepts in the learning process. Difficulties arise when the concepts are applied to a specific project in the field where engineers need to rely on observations and testing opposed to making assumptions. This is why the natural deductive teaching approach used by professors is often times misleading and

discouraging for students. The bridge between fundamental concepts and theories of engineering and how to apply them in real world applications is never built, which puts the student at a disadvantage when first entering the work force [1]. In order to reach a broader range of students, it is important that professors integrate both inductive and deductive teaching approaches within their course. Studies show that inductive learners retain material for longer periods of time, portray strong problem solving abilities, and possess enhanced reasoning skills [1].

Incorporating inductive and deductive teaching is especially important in the disciplines of geotechnical engineering, soil mechanics, and foundation engineering. Lab experiments, simulations, and visuals are necessary to fully understand the material, however, lab equipment is not always available for students to utilize. The purpose of this study is to design and build a lab demonstration to be implemented into geotechnical engineering courses that can effectively coincide with class lectures. The area of focus was the process of liquefaction and resulting soil behaviors due to this process. A senior design team of three undergraduate civil engineering students performed the research and developed a lab demonstration to be constructed. The goal of the demonstration is to provide students with a more thorough understanding of introductory soils mechanics concepts in the classroom by utilizing visual simulations.

The instructor and his student coauthors really care to help inspire and motivate students and geo-professionals review and learn soil mechanics [7] as they strongly believe that personal (participation) experience means everything which is very important in his or her future professional career advancement.

In the following sections, we briefly review the senior design background, report the design of effective stress and upward seepage laboratory demonstration budget and schematic design materialization and project schedules. Significance of the project is highlighted with pertinent concluding remarks and conclusions drawn at the end.

Background

Any time a structure is being built, it requires an extensive amount of planning by engineers of multiple disciplines and every building project always begins with the foundation. A structure is only as strong as the foundation upon which it is built, which is why it is so important that subsurface investigation of the underlying soil is performed prior to building. Soil investigation allows engineers to determine the physical properties and the behavior of the soil in order to determine if a construction site is sufficient to be built on. This is done by obtaining soil samples at different depths underground and performing laboratory testing on the samples. Failure to perform a soil investigation can result in foundation settlement of buildings, embankment failures on bridges and highways, or the overall collapsing of a structure [2]. Any of these catastrophic events increases the cost of the project and jeopardizes the safety of the general public.

One geotechnical phenomena that the senior design team focused the bulk of their research on was the process of liquefaction. Liquefaction occurs when the behavior of

soil changes from a solid to a liquid. When water travels upwards through the voids between soil particles, the pore water pressure increases in the opposite direction of the over bearing load, reducing the effective stress of the soil. The process of water flowing in the direction of the surface through a permeable soil specimen is known as upward seepage [3]. Studying these fundamental concepts and theories within soil mechanics, students can understand *why* liquefaction occurs, but understanding *how* the process occurs isn't as easy without being able to visually see the process take place. By developing an interactive laboratory demonstration that can simulate the process of liquefaction, connections can be made by the students from theoretical studies learned in lectures to how they are applied in practical engineering situations. Analysis of a small-scale model like this one allows geotechnical engineers to study soil behavior with different amounts of water being present underground with little cost and allows for future ground improvements to be made.

Design of Effective Stress and Upward Seepage Laboratory Demonstration

The laboratory demonstration incorporates key concepts learned in introductory soils mechanics and soils engineering courses, such as upward seepage of water through a soil specimen and the resulting behaviors of the soil that can result in the process of liquefaction. Upward seepage could induce a quick condition commonly exhibited in saturated sand with excess pore pressure. This is also known as a static liquefaction as differentiated from seismic liquefaction [3]. Quick condition is a very important concept and idea that any civil and in particular geotechnical engineering students needs to understand and master. For example, the special soil/ground improvement technique could utilize the same concept introduced in the paper.

The demonstration, seen in Figure 1, was developed to serve as a visual simulation as well as an interactive experience for students by allowing them to act as a structure and stand on a soil specimen undergoing liquefaction to get a first hand understanding of what occurs.

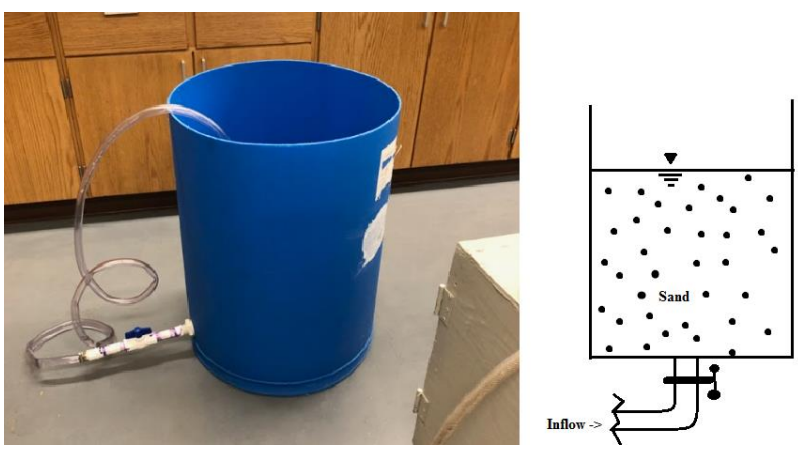

Figure 1. Laboratory Demonstration (Left). Laboratory Design (Right).

The demonstration was constructed using a 55-gallon industrial barrel. The team then cut the barrel to size and cut out a small diameter hole at the bottom of the barrel. Next the

team constructed an inlet out of PVC pipe and appropriate fittings. A shut off valve was added to the inlet to control the incoming flow. The barrel was then filled to two-thirds volume with sand. By providing an inlet at the bottom of the barrel, water can be pumped at a constant rate into the soil specimen. As the water begins to flow through the soil particles, the process of upward seepage can be observed. As the pore water pressure increases within the soil, the overall effective stress of the soil is reduced and the soil is visibly weakened.

The cost to build this demonstration and schedule of the design team can be seen in Table 1 and Table 2, respectively.

Table 1. Material List for Liquefaction Lab Set-Up.

Materials List		
	QTY	Price
55 Gallon Barrel	1	Donated
3/4" Vinyl Hose	20'	$9.00
Bulkhead Fitting	2	$10.00
PVC Glue	1	$5.00
PVC Primer	1	$6.00
3/4" PVC Fitting	2	$5.00
Ball Valve	1	$5.00
Brass Hose Barb	1	$2.00
3/4" PVC Pipe	10'	$7.00
	Total:	$49.00

An addition of external static load to the surface, in this case a student, will increase the rate of liquefaction. The students foot load could be simulating external construction or traffic load or borrowed fill load exerted on a certain civil/geotechnical engineering project.

Accompanying lecture notes from a classroom with a simulation depicting lessons learned enables students to completely grasp a full understanding of the topic as well as gain a greater interest in the subject.

Table 2 briefly shows how the senior design team did their literature research study, documentation of their findings. Based on their literature review, students were required to give presentation of their design progress to their academic adviser and course instructor. In the whole mean process, the senior design teams keep close contact with the adviser and reading pertinent journal papers assigned related to the design project.

Table 2. Design Team Schedule.

Task	Start Date	Completion Date
1. Documentation	9/1/2017	5/4/2018
2. Develop Design for Lab Demonstration	11/28/2017	3/28/2018
2A. Determine Location	11/28/2017	1/20/2018
2B. Develop Schematics	12/5/2017	12/10/2017
2C. Build Demonstration	2/5/2018	2/27/2018
2D. Test and Adjust Demonstration	3/21/2018	3/28/2018
3. Develop Design for Seepage Tank	10/24/2017	3/28/2018
3A. Determine Water Feed Method	10/24/2017	10/31/2017
3B. Determine Dimensions and Parts Needed	10/31/2017	1/23/2018
3C. Construct Tank	3/2/2018	3/21/2018
3D. Test and Adjust Tank	3/21/2018	3/28/2018
4. Develop Lab Manual	3/21/2018	4/7/2018
5. Write User Manual	4/7/2018	4/20/2018

Significance of Project

Constructing a laboratory demonstration that directly correlates with important geotechnical concepts provides students with confidence in their ability to fully grasp difficult engineering ideas and to apply the same idea to a similar or completely different project. For example, Li and Zeytinoglu (2018) report their instructional experience and findings on incorporating a highway fill embankment slope movement overlying a buried kettle lake which exhibits a large scale mother natured created static liquefaction quick sand conditions which eventually leads to slope movement failure [6]. The reported case study has been used for another senior design team to investigate the slope stability analysis and engineering design recommendations which is immediately tied to the current senior design project results and findings.

Such a laboratory demonstration reported in this paper also allows professors to combine inductive and deductive teaching approaches in order to contribute to effective learning by the students. Harry Cooke, from Rochester Institute of Technology, performed a study in 2009 on the effectiveness of geotechnical engineering demonstrations in introductory soils mechanics courses. He added five different demonstrations to the class involving different topics from the course. At the end of the course, he issued a survey to the students containing questions regarding the effectiveness of the course and how the students rated the course and the professor. These questions were answered on a scale from 1 to 5, 1 meaning, “strongly disagree” and 5 meaning, “strongly agree.” These questions were converted into a graph format showing the ratings from students from

2005 to 2009. The overall trend was increasing, meaning that after the demonstrations were implemented into the course, the students gave the questions an overall higher rating [4]. Professor David Elton well-known magic little books Soil Magic and Grounded have many amazingly effective classroom demonstrations of soil mechanics which is recommended to any civil engineering students and geotechnical engineering educators [9].

The lab demonstration built by the senior design team can also have a positive impact outside of the classroom. Access to new lab equipment that easily demonstrates core fundamentals during introductory freshman courses, open houses, and K-12 outreach events could attract more high school students, increase the number of applicants for the School of Engineering, and increase retention numbers within the university. This demonstration can help expose students to a higher subject matter and in turn a high level of thinking, which can greatly affect their net outcome from a course [5]. Using equipment designed and constructed by engineering students themselves will encourage more students that are already enrolled to get involved in similar projects within the school of engineering.

Helping students really master and learn important soil mechanics and soil engineering principles and concepts – effective stress and upward seepage and their visual and "sensational" effects of quick sand demonstration has additional far reaching effects and will be very important in their future careers. The demonstrated effective stress concepts could also be used in developing new ground improvement technique and equipment such as the compaction by vibroflotation process [8]. The developed laboratory can also help connect between classroom knowledge and real world seepage issues. This paper and Li and Zeytinoglu (2018) writings partly help bridge the connection of engineering geology class and demonstration of how risky the danger is if ignoring or neglecting to pay the attention of fundamentals of geotechnics, herein quick condition static liquefaction induced by mother nature with proper engineering geology situation overlying a kettle lake [6]. The developed laboratory demonstration equipment could also be improved for potential future research topics for MS and/or PhD graduate students interested in studying the static liquefaction triggering mechanism. Last but certainly not least, it can also be used as demonstration laboratory activities to help attract more high school students to attend Purdue University Northwest to study civil and geotechnical engineering programs.

Concluding Remarks

The importance of active, hands-on learning for students studying a discipline in the STEM industry is becoming more and more relevant every year. There is a conflict between university professors and students in regard to the methods of teaching and learning that works best for an individual. It is in human nature for us to have an inductive approach to learning whereas professors often fall into the deductive approach to teaching. This contradiction serves as a barrier for effective learning amongst the students, especially those studying engineering. This is especially true for geotechnical engineering and in understanding soil mechanics where students are constantly studying

engineering principles that are not easily accessible to observe or visible because it all occurs underground. The connection between theories of *why* things occur is not easily connected with *how* they occur. In order to do so, a senior design team at the university developed, designed, and constructed an interactive laboratory demonstration that shall be utilized in a soils engineering curriculum to aid in the understanding of important concepts, such as liquefaction, upward seepage and effective stress. A separate paper [6] utilizing a high way fill embankment overlying a kettle lake has been used to partly help connecting the missed link by connecting the classroom lectures and real world projects failure. The reported laboratory scale quick sand static liquefaction in this paper helps reinforce and enhance the soil mechanics instructions.

The laboratory demonstration will increase the amount of time students can spend actively studying, observing, and analyzing real world soil mechanics phenomena that could not otherwise be done. It also demonstrates the importance of soil investigation prior to construction beginning on a project for students wishing to further their education in geotechnical engineering. Future studies will need to be performed once the demonstration is implemented into the courses in order to determine if the demonstration served its expected purpose. It is the intent of the design team that future studies will show more opportunities for students to get hands-on experience within the university can help attract more high school students and retain currently enrolled students to STEM programs at the university and improve the professor-student relationship within the engineering education system.

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