Liquefaction Demonstrations – A Student Project

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Abstract

The recent increase in catastrophic earthquakes (latest India Gujarat Earthquake, 2001) and the repeated evidence of ground failure due to liquefaction motivated this student research project. Liquefaction is a soil mechanics problem that often impacts structures that are supported on saturated sand deposits. The large deformations of the foundation soils typically cause major failures of civil engineering structures. This project involved research of the liquefaction phenomena and the impact experienced on select recent earthquakes. Additionally, the design of an experiment demonstration will be completed during the academic year. The device will be a feature laboratory demonstration to inspire students interested in earthquake engineering. A student was guided to research the literature on soil liquefaction and performed simple exercises on how liquefaction occurs. Once the student developed a working knowledge of the liquefaction phenomena the design of a liquefaction demonstration device was initiated. The student developed design drawings (AutoCAD and to scale) to be used in building the device in conjunction with the departmental machinist.

Introduction

In the past two years our society has experienced a number of major earthquakes (e.g., Chi-Chi Taiwan, 1999; Kocaeli, Turkey, 1999; El Quindio, Columbia, 1999; Bhuj, India, 2001; and El Salvador, 2001) with significant strong ground motions causing profound damage to communities around the world. Closer to home, the recent U.S. earthquakes (e.g., Northridge, California, 1995 and Nisqually, Washington, 2001) have raised the awareness in the research and disaster management organizations. The National Science Foundation is currently soliciting proposals in a second phase to complete a Network for Earthquake Engineering Simulation (NEES), which will consist of distributed research experimental and computing resources brought together by a national network for virtual earthquake simulation (http://www.nees.org). Conceivably, more researchers will have available to them sophisticated resources for earthquake research. So, as academicians we have the responsibility to motivate student interest in earthquake engineering. The University of Missouri-Rolla (UMR) is contributing to this national need by recently completing a project[1] for the Missouri Department of Transportation and a recently awarded grant from the Federal Highway Administration. These projects are focused on assessing the seismic vulnerability and remediation of highway bridges in MidAmerica. UMR has also formed the Natural Hazards Mitigation Institute (NHMI) to provide research mechanisms to focus these efforts on campus.

The Mississippi Embayment (in southeast Missouri) is the largest single liquefaction area in the continental U.S., presenting a large geohazard in the Midwest. Liquefaction is a geohazard often not understood by civil engineering students, even after an undergraduate course in soil mechanics. Approximately 10 months ago, during an advising session with an undergraduate student, the conversation turned to one of the current research projects in earthquake engineering. Soon, both student and faculty were developing a proposal to engage in research/design related to earthquake engineering. The project was intended to have a hands-on experience outside of the classroom, however, collecting academic credit. One of the outcomes of the project is to deliver a "liquefaction tank" to be used in demonstrations during class and laboratory sessions. The situation was ideal for implementation in the Opportunities for Undergraduate Research Experience (OURE) program at UMR.

Preparation for OURE Project

The Opportunities for Undergraduate Research Experience (OURE) program at UMR was established by the Office of Academic Affairs under the direction of the Provost. The goals of this program are to:

- expand opportunities for a more active form of learning by students,
- encourage the interaction of undergraduate students with faculty,
- expand the level of research activity on the campus,
- help recruit superior students into graduate programs, and
- demonstrate that teaching and research are compatible and mutually reinforcing.

The faculty agrees to supervise the undergraduate student as junior colleagues in their research projects, both during the summer session and during the academic year. The faculty member and student provide brief synopses of potential research project(s) to the office of academic affairs via the departmental coordinators. The student signs the two-page proposal and commits to complete the research in the form of a scientific paper (see actual proposal, Appendix 1). If the student is awarded the OURE project the office of the Provost makes the award by providing a stipend to the student including some funds for minor research expenses.

In the case of this project, an undergraduate student (sophomore) with interest to get more involved with the department applied for the OURE even before he had taken any courses in geology or soil mechanics. His interest was on the design-build experience of laboratory equipment and earthquakes. There were some uncertainties on the success of the project without the minimum background, but given the past success of the student in other courses (GPA 3.9) the project was a GO, and got funded by the Provost's office.

The project was setup by initially completing a guided literature review, learning fundamental concepts in soil mechanics and liquefaction, and preliminary design in the fall semester. This was particularly challenging since the student was enrolled in 18 credit hours.

Background Research

The student was not enrolled in a course for academic credit for this research activity in the first semester (Fall). However, significant progress was made after hours and weekends. Assigned reading initially from textbooks and websites were completed, followed by Q&A sessions with the advisor to get a fundamental understanding of the problem. As the semester progressed, it was evident that the independent research was put aside to keep up with the student's regular coursework. Then, the strategy was modified to include weekly meetings with the student complemented by off-campus site visits and laboratory hands-on experience.

Learn from Past Experiences

The liquefaction demonstration tank is not anything new. In fact, it's a classic in a geotechnical engineering program. This demonstration experiment tends to leave a lasting impression on the students mind, as it did to the author twenty years ago. As recent as this month, email inquiries from professional engineers are being made to faculty on how to build one of these liquefaction tanks for use in the upcoming 2002 Engineer's Week. The email inquiry shown below was made to Professor Kovacs[2], who forwarded to the author since he was aware of the current project:

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> I am sure you would not remember me, as you have had many students over
> the years, but I graduated from URI in December of 1993 from the College
> of Civil Engineering.  I am heading a committee for Engineer's Week in
> the State of New Jersey, and we are coming up with ideas for exhibits
> for 7-10 year olds.  One of the things I always remembered from your
> class was your demonstration on liquefaction, with the house falling
> through the sand.  I thought this might be an appropriate demonstration
> for an exhibit.  With this is mind I was hoping you could help me.
> ^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
> Scott Lubarsky, P.E., New Jersey.
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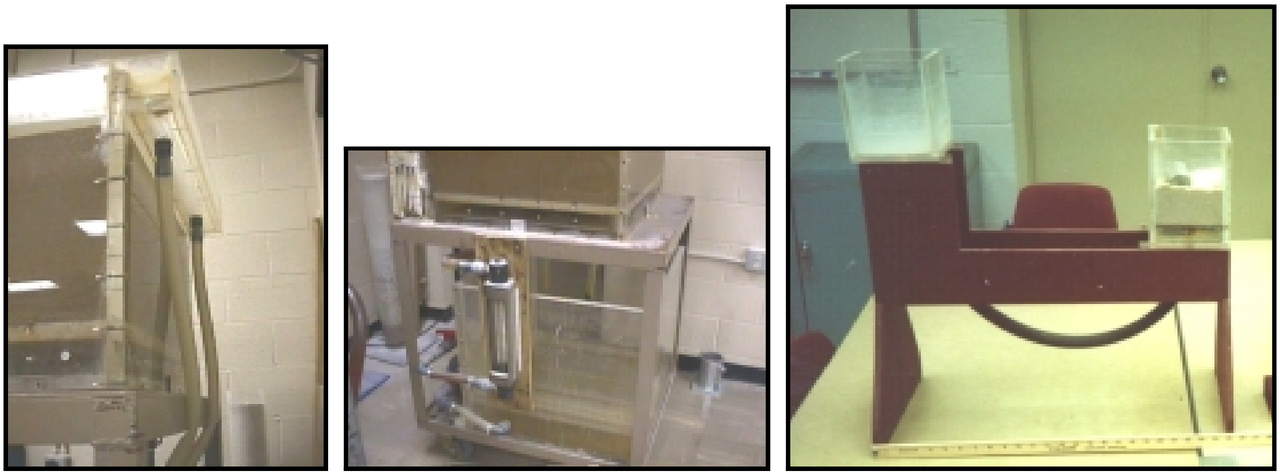
The principle of effective stress initially introduced by Terzaghi in the 1930s is what needs to be mastered by students before they can understand liquefaction. Terzaghi's simple arithmetic expression, where the effective stress is equal to the total stress minus the pore water pressure ($\sigma' = \sigma - u$) is what's taught in an undergraduate soil mechanics course. In saturated sands the pore water pressure is equal to the hydrostatic pressure. During an earthquake, the pore water pressure increases beyond hydrostatic due to the dynamic loading, bringing the effective stress to zero. This in turn, causes the shear strength ($\tau = c + \sigma'\tan\phi$) to also be reduced significantly like a liquid and make the soil unable to bear shear load, hence the term liquefaction. As simplistic as it may sound, liquefaction is still one of the most researched topics in geotechnical earthquake engineering, since the material changes from semi-solid particulate media to a non-linear viscous material. Understanding the behavior of the material during this dynamic phenomena and how to mitigate its consequences is very challenging task.

So, keeping young engineers aware of the importance of liquefaction and its consequences remains a key educational objective in civil engineering. The student took a trip during one of the breaks to visit other universities to see their version of liquefaction tank. Additionally, faculty members from other universities were contacted to contribute with photographs and existing plans, if available. Figure 1 shows two photographs of the liquefaction tanks used at other universities.



(a) (b) (c)

Figure 1 – Liquefaction tanks at other Universities,
(a) U. of Illinois, top half (sand box); (b) U. of Illinois, bottom half, (water tank);
(c) U. of Rhode Island, (both water and sand box at different elevations).

Essentially, the concept is similar in both tanks shown in Figure 1. There are two separate containers, a tank with water that will be used to fill and drain the sand box. Once the sand is saturated a dynamic load (via rubber hammer or vibrating motor) is applied to increase the pore water pressure and induce liquefaction. The liquefaction tank from the University of Illinois is a laboratory version based on the design concept presented in a textbook[3]. This design consists of a 24-inch cube sand box. Below the sand box is a water tank that with the use of a pump saturates the sand from the bottom to the top. The University of Rhode Island liquefaction tank (Figure 2c) is a classroom version (portable) with a tank on the left that saturates the sand on the right by controlling the hydraulic head. Then the dynamic load is applied to induce liquefaction.

Trials and Prototype

Based on the limited instruction (close to none), research and visits the undergraduate student was assigned to build a small prototype liquefaction demonstration tank by the end of the fall semester. He was made responsible of the design and construction with the assistance of our departmental senior machinist. At the time when the trials and prototype were underway, a new booklet entitled *Soils Magic*, was published by ASCE[4]. This booklet has a couple of examples and step-by-step instructions on how to perform the liquefaction "magic". The student tried using a thin walled plexi-glass bin and it leaked. Then he tried a plastic concrete cylinder mold and it worked, but it lacked the visual effects of a transparent container. Finally, he became challenged when he found scrap pieces of plexi-glass in the machine shop that were hefty enough to make it impermeable and eventually mount on the new instructional shake table purchased at UMR. Figure 2 shows a composite of the different line drawing views of his preliminary design as the prototype. Based on these drawings and interaction with faculty and the machinist the student built the sand box with inlets/outlets and drains for saturation and a water reservoir. The prototype model was very similar to the University of Rhode Island version.

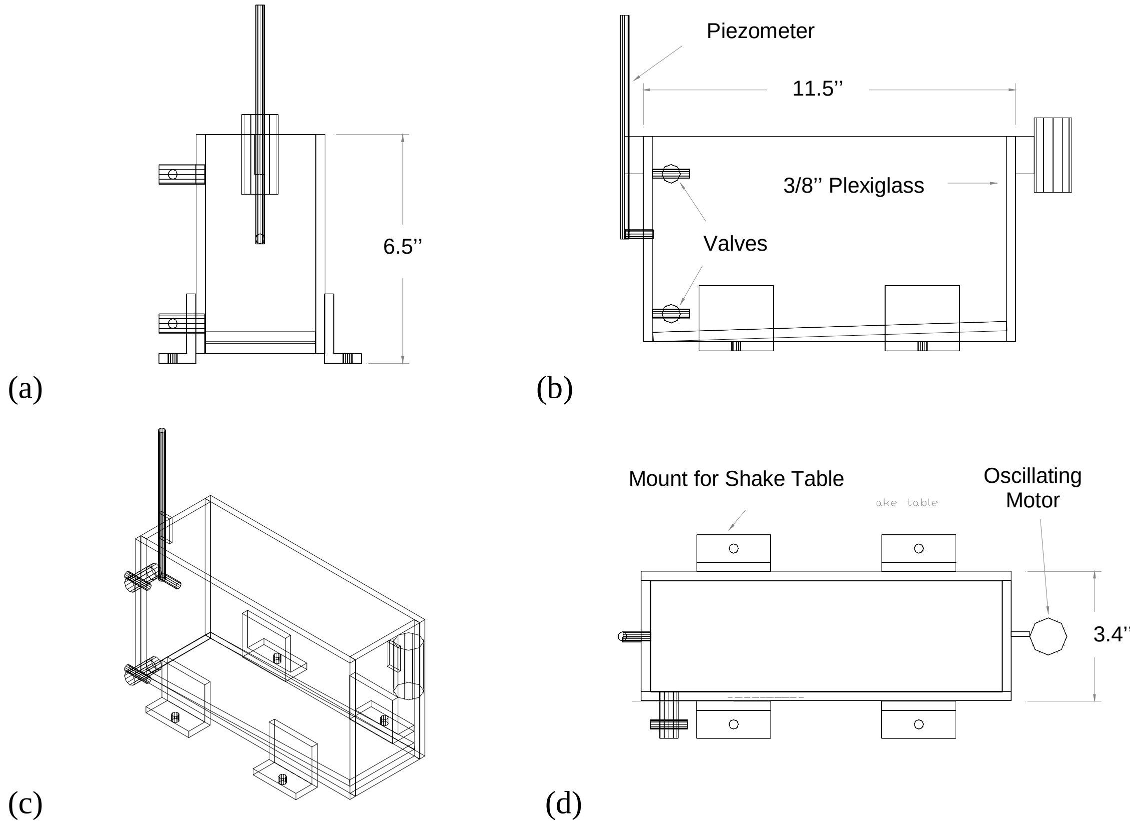


Figure 2 – Drawing for the Prototype (a) front view, (b) side view, (c) isoparametric view, and (d) top view (all by Wes Merkle)

The plan is to mount this prototype on the shaking table shown on Figure 3, by means of four aluminum brackets. The shake table has a payload of 25 pounds, which limits the size of the liquefaction tank. Alternatively, the liquefaction dynamic load can be induced with a motor oscillating a weight attached to a wall of the box. For the use with the motor, the base of the box should be supported on absorbing pads that will allow movement of the box.

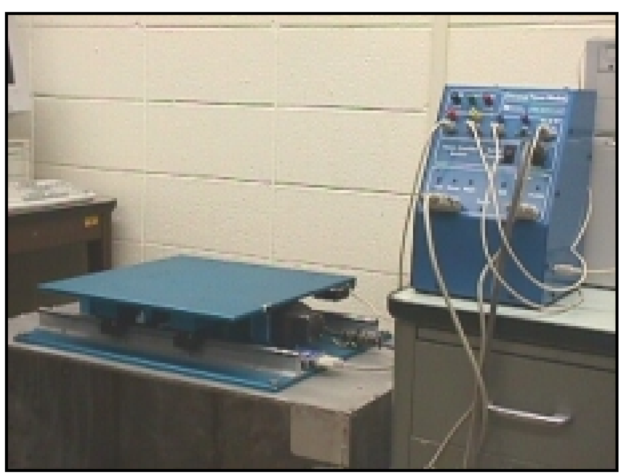


Figure 3 – Instructional Shake Table at UMR (by Quanser Consulting)

Figure 4 shows photographs of the prototype model as of December 2001. More photographs and movie files are posted on the Internet (http://www.umr.edu/~rluna/liq_tank) and will be further developed by the student in the Spring of 2002.

Figure 4 – Trials with the Built Prototype – saturating sand.

Final Design-Build

The plan is to design and build the large liquefaction tank (laboratory version) this coming semester, Spring 2002. During this semester the student will enroll in a 3-hour course entitle "390H - Undergraduate Research" enabling him to spend more steady time on the project and earn academic credit. The whole experience will be developed into a website and design plans will be made available for download. Our experience during this research was that other authors and Universities do not have design plans for this type of liquefaction tank. The small prototype version will remain for use with the instructional shake table and to bring into the classroom for demonstrations.

The semester following the design of the prototype demonstration, this liquefaction tank was used twice, one time in the classroom for the CE 215 Elementary Soil Mechanics course to demonstrate the effect of increased pore pressure in a soil deposit. The excess pore pressure was generated with the dynamic load such as that of an earthquake. This demonstration took place when the class was in the process of learning the theory of consolidation, which in turn, requires an understanding of the process of excess pore water dissipation. This demo generated more discussion than any other example presented in class. In closing, the author considers that the progress made by the student during the one semester was significant considering his course load. The learning that goes hand-in-hand with the progress made was mostly done experimentally and making reference to published work. Needless to say, the faculty-student relationship changed from advising to mentoring, two very different relationships[5]. The student will continue making progress and following the already developed skills of research and experimentation, will have the satisfaction of building an experiment to be used by other students in his alma mater.

Acknowledgements

The author would like to thank Mr. Wesley Merkle for all his hard work and allowing me to write about his experience from the faculty point of view. The financial support from the Office of Academic Affairs and the Department of Civil Engineering is also acknowledged. Thanks also go to Steve Gable, Sr. Engineering Tech., who has always been very helpful in our small and large projects with students. The input and contributions of other faculty, such as: Dr. W. Kovacs, Dr. S. Prakash, Dr. R. Stephenson, Dr. R. Holtz, Dr. D. Elton and Dr. Y. Hashash are also acknowledged.

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Biographical Information
Ronaldo Luna is an Associate Professor of Civil Engineering at the University of Missouri-Rolla. He teaches soil mechanics and foundation engineering at the undergraduate and graduate level. His research spans from GIS and imaging applications in geotechnical and environmental engineering to site-specific studies on the behavior of soil deposits during earthquakes. For further information please visit: http://www.umr.edu/~rluna

Appendix 1 – OURE Application Form (next pages)

APPLICATION FORM

UMR UNDERGRADUATE RESEARCH (2001-2002)

PROJECT TITLE: **Liquefaction Demonstration – Research and Design**

PROJECT DESCRIPTION:

The increase in catastrophic earthquakes in recent years (latest India Gujarat Earthquake, 2001) and the repeated evidence of ground failure due to liquefaction has motivated this research project. Liquefaction is a soil mechanics problem that often impacts structures that are supported on saturated sand deposits. The large deformations of the foundation soils typically cause major failures of civil engineering structures. This one-year project will involve research of liquefaction phenomena and its related impact on select earthquakes. Additionally, the design of a demonstration experiment will be completed during the academic year. The built device will be a feature lab demo to outreach to other students that may have an interest in earthquake engineering. The support of the Civil Engineering department in the construction of this device and matching for the equipment and supplies as well as machinist time has been secured.

PROPOSED DURATION:	X	Summer 2001	X	Fall 2001	X	Winter 2002

STUDENT'S ROLE IN PROJECT (Provide detailed description):

The student will be guided to research the literature on soil liquefaction and will perform simple exercises on how liquefaction is evaluated based on geotechnical in-situ and laboratory measurements. Then the impact of the ground deformations on to structures will be investigated. Once the student has a working knowledge of liquefaction phenomena the phase of design of the liquefaction device will be initiated, probably through the fall semester. The student will develop design drawings (preferably AutoCAD quality to scale) to be used in building the device in conjunction with the CE machinist (Steve Gable). Parts and equipment will also be ordered in the fall to commence construction of the device in the spring semester. At the end of the project the student will summarize his findings in writing in the format suitable for submission into a undergraduate paper competition for publication.

Student: **Wesley J. Merkle**	Student's Signature:	____________________
Rolla Phone: (573) 341-xxxx	Social Security Number: XXX-XX-XXXX	
Rolla Address:	Farrar 318A 601 W. 10th Street Rolla, MO 65401	
Student Number: xxxxxx	Cumulative GPA: 3.929	Credit Hours Completed: 75
E-mail address: xxxx@umr.edu		
Supervisor: Dr. Ronaldo Luna	Supervisor's Signature:	____________________

(continues)

BUDGET:
Student Stipend:

Summer 2001	--	Fall 2001	$500	Winter 2002	$500

Supplies/Travel:	$ 500	(Detail and justify if more than $200) – The student will be need access to funds through the advisor to purchase supplies for the construction of the liquefaction device. Additionally, the organization: Earthquake Engineering Research Institute (EERI) holds annual student paper competitions for work performed by undergraduate students and funding for travel is usually cost-shared by the academic institution.
Total Amount Requested:	$ 1,500	
Additional Funding From Other Sources:	$1,000	Department of Civil Engineering towards the purchase of materials and equipment.

ACADEMIC CREDIT:	Course Number	CE 390 H	Number of Hours	3

SEND TO:	OFFICE OF ACADEMIC AFFAIRS, 204 PARKER HALL

APPLICATION DEADLINE: 3/09/01 (SELECTIONS MADE BY 4/21/01)