AC 2009-1041: AN AFFORDABLE CYCLIC TRIAXIAL SYSTEM FOR NONRESEARCH UNIVERSITIES

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AN INEXPENSIVE CYCLIC TRIAXIAL SYSTEM FOR EDUCATIONAL UNIVERSITIES

Abstract

Liquefaction is the term commonly used to describe the sudden, dramatic strength loss that sometimes occurs in soils during seismic loading. While most frequently associated with cohesionless soils such as sands and silts and the dynamic loadings due to earthquakes, it has been reported in many types of soils under both dynamic and static loadings. As the built environment grows, its susceptibility to seismic damage is increased proportionally, thus the need for training engineers in seismic behavior and design, and the need for research in these areas, also increase. Unfortunately, due to the high cost of dynamic soil testing equipment, few students are able to have hands-on experience with this type of soil testing. Dynamic soil testing equipment such as cyclic triaxial and cyclic simple shear machines typically ranges from $60,000 to $200,000. As a result, typically only students at large research universities have any exposure to this type of testing and only those performing research have anything more than an observational experience.

The apparatus discussed in this paper reflects the author's attempt to develop an affordable dynamic soil testing system (less than $10,000). Such a system will make the study of dynamic soil behavior available to students at small universities and at universities in developing countries who cannot afford to purchase such equipment. The paper outlines the design and construction of a cyclic triaxial machine that can be constructed by universities that lack the large research budgets to purchase such equipment. Such a device will allow students at smaller universities the opportunity to study the dynamic behavior of soils first-hand and to develop viable undergraduate research programs in this area.

In addition to the information on the system provided in the paper, the author will freely provide, through a website, schematics of the system, software for controlling and monitoring the system (written using the computer software Labview), and guidance in setting up and operating the system.

Introduction

Earthquakes pose one of the greatest natural threats known to the human race. They pose a threat to citizens of almost every country on the planet. Within the last few years, earthquakes have claimed tens of thousands of lives in China, Pakistan, and Central America alone. The December 26th, 2004 tsunami, triggered by a magnitude 9+ earthquake off the Sumatran coast, claimed over 225,000 lives in eleven countries. Even developed countries are not safe from the impacts of earthquakes. The January 17th, 1994 Northridge earthquake killed 72, injured more than 9000, and caused an estimated $44 billion in damages. Exactly one year later, the Kobe Earthquake in Japan killed at least 5100 and caused over $200 billion in damages.

The world's infrastructure is at constant risk from earthquakes. Structures that are founded on or built out of soils are particularly vulnerable due to the nature of the material. The behavior of soils during seismic events is largely controlled by the behavior of the water pressures within them. As these water, or pore, pressures rise, the strength of the soil decreases, leading to increased deformation of the soil mass. If the pore pressures become large enough, the soil is said to "liquefy" and it acts as a viscous liquid with little or no shear strength. In order to predict the behavior of a soil mass subjected to seismic loading, it is necessary to accurately model its pore pressure response.

Unfortunately for schools with limited equipment budgets, the equipment required for dynamic testing of soils is very expensive, with cyclic triaxial machines costing upwards of $60,000 and cyclic simple shear machines costing more than $100,000. As a result, students at non-research schools rarely have the opportunity to study the behavior of soils under cyclic loading. This problem is even worse for students in developing nations, who are often at higher levels of risk from seismic events than their counterparts in more developed nations.

In response to the need for relatively affordable dynamic soil testing equipment, the author has developed a cyclic triaxial system that can be constructed for a cost of less than $10,000. Such a device would allow students at smaller universities the opportunity to study the dynamic behavior of soils first-hand and to develop viable undergraduate research programs in this area.

The system can either be built from scratch or created by modifying an existing triaxial apparatus to apply cyclic loadings. The software for controlling the loading and the data acquisition system is written in Labview. This software and schematics of the system are available for public use by educational institutions through the author's website.

Background

Liquefaction is the term commonly used to describe the sudden, dramatic strength loss that sometimes occurs in soils during seismic loading. While most frequently associated with cohesionless soils such as sands and silts and the dynamic loadings due to earthquakes, it has been reported in many types of soils under both dynamic and static loadings.

Liquefaction of soils in the field is evaluated either by in situ testing or by laboratory testing. Both liquefaction evaluation and parametric studies of the factors affecting liquefaction are performed in the lab using cyclic triaxial tests.

Cyclic triaxial tests are used to model the loads applied to a soil mass by an earthquake. The liquefaction resistance of a soil is often measured in the laboratory using reconstituted specimens tested in cyclic triaxial tests. The specimen is formed within a latex membrane inside the triaxial cell, saturated, consolidated to some stress condition and then loaded axially with a pulsating deviator load. As the deviator load cycles between compression and tension, water pressures in the specimen increase, the net or effective stress acting on the specimen decreases, and the specimen undergoes axial straining. The specimen is said to have liquefied when either the water pressure inside the specimen becomes equal to the initial confining stress.

The ability of a soil to resist liquefaction is evaluated by comparing the cyclic loading required to cause liquefaction in some number of cycles to the cyclic loading expected to be applied in the field. This evaluation is performed using cyclic triaxial tests as follows:

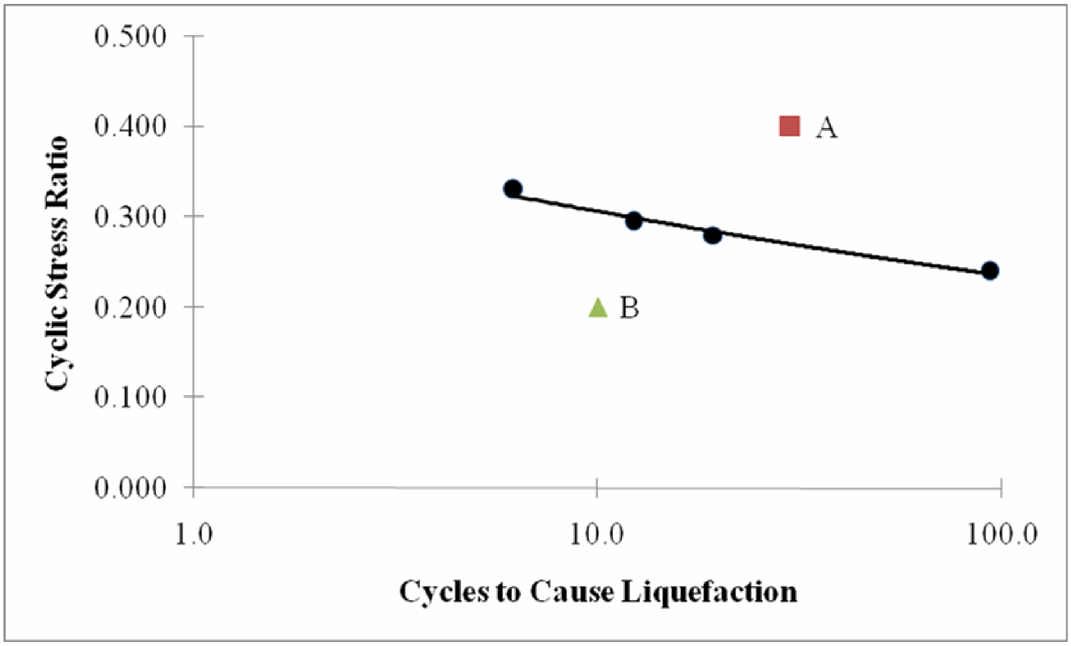

Figure 1: Cyclic Resistance Curve (after Mulilis, Chan and Seed[1])

1. Several cyclic triaxial tests are performed at different cyclic stress ratios (CSRs). The cyclic stress ratio is the ratio of the applied shearing stress to the effective confining stress. In a cyclic triaxial test, the applied shearing stress is one-half of the applied deviator stress. Therefore the cyclic stress ratio is simply the ratio of the applied deviator stress to twice the initial effective confining stress.

2. The CSR applied in each test is then plotted against the number of cycles of deviator stress required to cause liquefaction in that test. This process is repeated for several cyclic stress ratios and a cyclic resistance curve is produced. A typical cyclic resistance curve for medium dense sand is shown in Figure 1 (after Mulilis, Chan and Seed[1]).

3. Once the cyclic resistance curve is developed, the number of cycles of loading expected to be applied to the soil in the field is estimated based on the design earthquake's magnitude.

4. Similarly, the cyclic stress ratio expected in the field is estimated based on the expected peak ground acceleration and the stresses acting on the soil element.

5. Once the field cyclic stress ratio and number of cycles to loading are predicted, they are plotted onto the figure containing the cyclic resistance curve. If they plot on or above the cyclic resistance curve, like Point A in Figure 1, the soil in the field is predicted to liquefy. If they plot below the cyclic resistance curve, like Point B in Figure 1, the soil in the field is not expected to liquefy.

The Apparatus

The system described herein is an electro-pneumatic system based on a design by Li, Chan, and Shen[2]. Back pressure saturation is performed manually by using the regulators on the pressure panel to control the back and cell pressures. Similarly, consolidation is controlled manually using the cell pressure regulator and the volume change device. The cyclic axial load is applied to the soil specimen using an electro-pneumatic transducer that is controlled by the control software, written in Labview, acting through the data acquisition card. Data acquisition is handled during saturation, consolidation and cyclic loading using Labview and the data acquisition system. A general schematic of the system is provided in Figure 2.

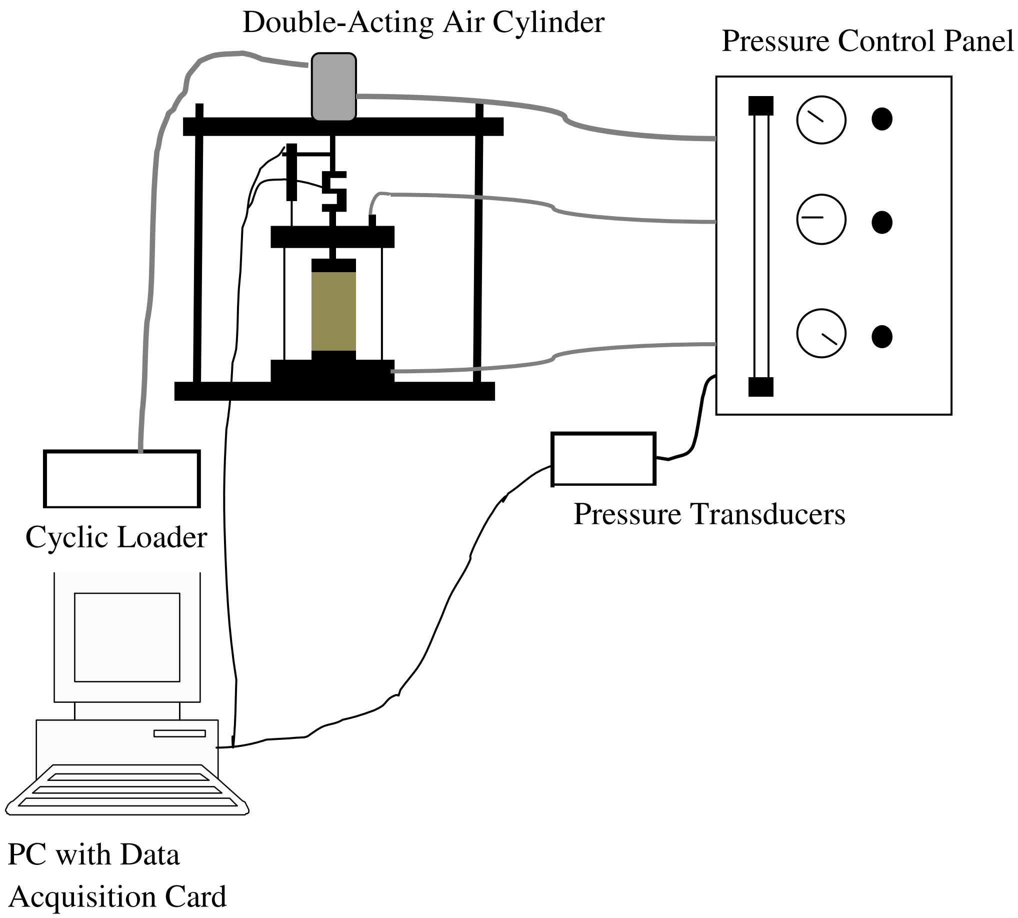

Figure 2: System Layout

Back pressure saturation of the specimen is necessary to ensure that all the soils voids are filled with water, so that pore pressures can be accurately measured. It is handled manually through the pressure panel, which is shown in Figure 3. Pressurized air is supplied to the panel from a compressor or supply line. The regulators on the panel allow the back and cell pressures to be adjusted allowing saturation to occur at a constant differential between the two pressures. Once saturation is complete the specimen is consolidated by increasing the cell pressure and measuring the water that flows out of the specimen. This allows the change in volume and density of the specimen to be determined. Two 100-psi differential pressure transducers are used to measure the back and cell pressures. A one-psi differential pressure transducer measures the volume of water contained in the volume change device by determining the pressure difference between the top and bottom of the water column, which allows the change in the volume of water entering or leaving the specimen to be monitored. All three pressure transducers are read using the data acquisition system.

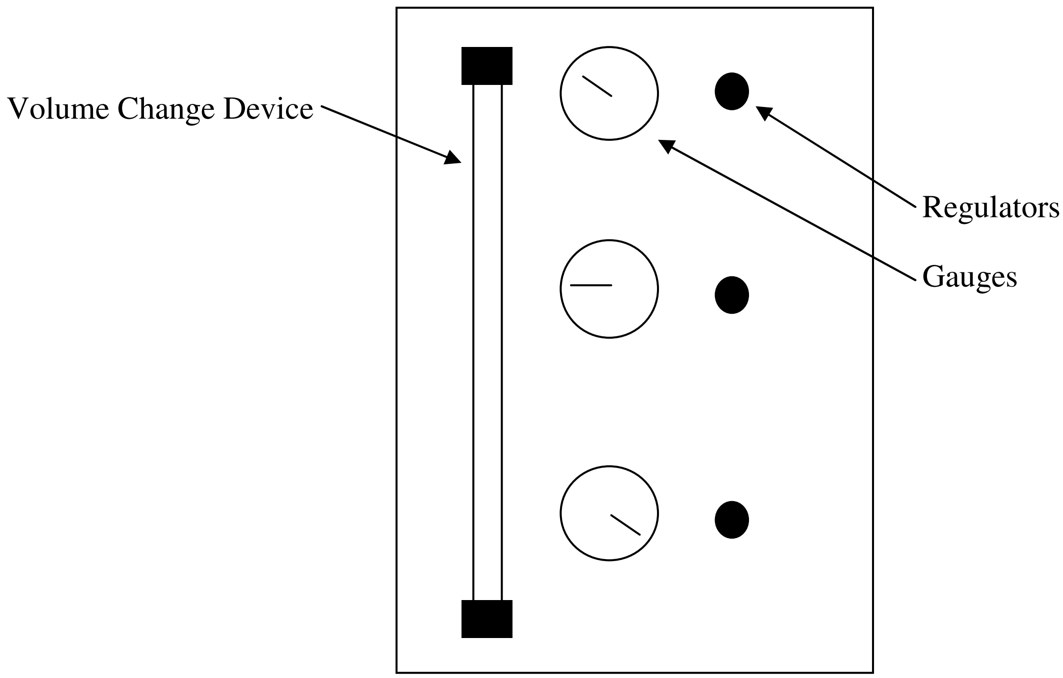

Figure 3: Pressure Panel

The cyclic load on the specimen is generated by a double-acting cylinder attached to the rod in the triaxial cell and thus to the specimen. The force exerted on the specimen by the piston is controlled by applying a steady pressure to the bottom half of the piston inside the cylinder and varying the pressure applied to the top of the piston. The magnitude of the steady pressure is controlled manually by a regulator located on the pressure panel. The pressure on the top of the piston is controlled by the cyclic loader shown in Figure 4. The control program generates a voltage that varies as a sine wave that is transmitted to the electro-pneumatic transducer. The transducer then varies the pressure applied to the volume booster, which in turn varies the amount and pressure of the air sent to the piston. During cyclic loading, the software monitors the load cell, LVDT and pressure transducers to record the stress, strain and pressures occurring in the specimen.

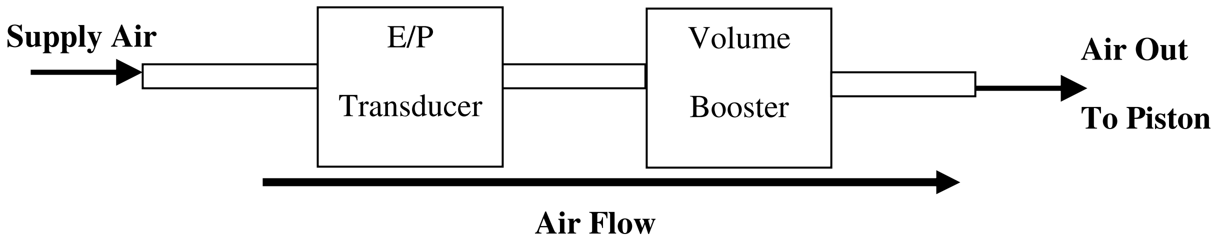

Figure 4: Cyclic Loader

Cost

The system described can be constructed for less than $10,000. An itemized cost breakdown is provided in Table 1. This cost can be significantly reduced if an existing triaxial apparatus is modified, if a computer is already available, or if a license for Labview software is already possessed

Availability

Plans and schematics for constructing the system described in this paper as well as the software necessary for controlling it can be downloaded through the author's website, which can be accessed through http://www.valpo.edu/engineering/programs/civil/faculty.php. They are intended for use by educational institutions and researchers, and is not intended for use by for-profit organizations.

Conclusions

The ability of students at schools without large research budgets to obtain experience in the dynamic behavior of soils and to possibly even perform research in the area is limited due to the cost of the equipment. The reduction of the price of such equipment from $60,000 or $100,000 to less than $10,000 will be of special benefit to universities and other agencies in developing nations who face serious earthquake–related threats, but cannot currently afford to purchase the equipment necessary to properly evaluate the soils in their region.

This paper discussed the design and construction of an affordable electro-pneumatic cyclic triaxial machine that can be constructed by faculty and students at universities that lack the large research budgets necessary to purchase such equipment. Additionally, it provides an Internet link that allows readers to access and download the software necessary for implementing such a system.

Table 1: Itemized Cost Breakdown

Item	Quantity Needed	Approximate Unit Cost	Approximate Total Cost
Computer	1	$1,000	$1,000
Labview software	1	$1,300	$1,300
Data Acquisition Card	1	$850	$850
Cable	1	$120	$120
Terminal Block	1	$300	$300
100-psi Differential Pressure Transducer	2	$550	$1,100
One-psi Differential Pressure Transducer	1	$550	$550
Gauges	3	$75	$225
Regulators	3	$75	$225
15 psi Electropneumatic Pressure Transducer	1	$300	$300
High Relief Volume Booster	1	$200	$200
Double Acting Air Piston	1	$250	$250
200-lb Load Cell	1	$350	$350
1-Inch LVDT	1	$350	$350
Triaxial Cell	1	$1,700	$1,700
Power Supplies	2	$100	$200
Valves and fittings	-	$500	$500
Tubing	-	$100	$100
Assorted Materials	-	$300	$300
Total			$9,920

Bibliography

1. Mulilis, J., Chan, C., and Seed, H., (1975). "The effects of method of sample preparation on the cyclic stress-strain behavior of sands," UCB/EERC-75/18, Earthquake Engineering Research Center, University of California, Berkeley, 1975-07, pp. 138.

2. Li, X. S., Chan, C. K., and Shen, C. K. (1988). "An automatic triaxial testing system." Advanced triaxial testing of soil and rock, ASTM STP977, 95–106.