Computer-Controlled Data Acquisition Laboratory Experiences in Civil Engineering Technology

Anthony L. Brizendine, Ph.D., P.E., P.S.
Fairmont State College

Abstract

This paper outlines the use of data acquisition in the Civil Engineering Technology laboratory. Very few CET soil mechanics laboratories currently introduce or utilize data acquisition as part of the instructional process. Not only is data acquisition useful in facilitation of expedient experimentation in an academic setting, knowledge of data acquisition is a marketable skill for CET students now and in the next century. Discussion of how the soil mechanics laboratory was developed, funded and instrumented is included. A series of NSF/WV EPSCoR grants were utilized to fully develop this laboratory.

Consolidation, hydraulic conductivity, direct shear, triaxial shear, unconfined compression, and data acquisition equipment was purchased, instrumented, and incorporated. Each test setup can be monitored through an elementary computer/data acquisition interface. Raw data is collected via the data acquisition system which is controlled by the HOST® Management System. Data can be reduced manually or automatically using GEOSYSTEM® computer software developed by Von Gunten Engineering Software, Inc.

One of the obvious benefits is time management; for instance, students can begin consolidation tests, collect data "through the night" and apply incremental loading the next morning while obtaining a full night's sleep. Discussion of the funding mechanisms, development difficulties, and benefits of using data acquisition and associated software in the undergraduate environment for CET courses will be provided.

Background & Inspiration

When the author arrived at Fairmont State College in the fall of 1991, he was given the responsibility of developing a sequence of geotechnical courses for the undergraduate civil engineering technology program. The previous TAC of ABET accreditation visit had recommended that the program provide practical hands-on laboratory experiences for CET students in the soil mechanics courses. Yet, as the author surveyed the "Soils Laboratory," he found little more than a sand cone, a couple proctor molds, a few sieves, a scale and an agricultural soil test kit used to determine ph levels. Even basics such as lab benches, sinks, water or air supply were not available. He quickly realized that to build an acceptable laboratory with the limited funds available would take decades rather than years; hence, he immediately began to look for alternative sources of funding.

The author discovered a program called the West Virginia Experimental Program to Stimulate Competitive Research (WV EPSCoR). This program, funded in part by the National

Science Foundation, supported programs and proposals that increased or enhanced opportunities for West Virginia undergraduate students to study science and engineering. Statewide funds for the EPSCoR program averaged about $50,000 per year in this program.

Funding Successes

The author immediately went about writing grants to secure funding to build a respectable soils laboratory. A series of WV EPSCoR grants were written and funded from 1992 to 1995, as follows:

Grant #1:	**Permeability and Consolidation Test Systems**	**$ 8,809.00**
Grant #2:	**Direct Shear Apparatus and Data Acquisition Equipment**	**$11,811.00**
Grant #3:	**Compression Test Equipment & Instrumentation**	**$12,000.00**

Total funding secured from the WV EPSCoR Instrumentation Grants Program was $30,720.00. These funds, which provided for big ticket purchases of advanced apparatuses and instrumentation, allowed departmental resources to be used for the purchase of elementary equipment such as liquid limit devices, sand cones, proctor molds and hammers, hydrometers, sieves, etc.

Utilizing Data Acquisition

Generally, it is the author's belief that most undergraduate civil engineering technology students are not exposed to advanced soil testing such as direct shear, triaxial shear, hydraulic conductivity utilizing flexible-wall permeameters, and, perhaps, even consolidation. And certainly, most CET students are not exposed to data acquisition systems and computer-controlled data acquisition. It is also the author's belief that exposure to data acquisition tools can be very rewarding undergraduate experiences. While students must become familiar with basic testing equipment, the use of modern, state-of-the-art equipment and data acquisition is extremely effective in stimulating interest in undergraduate laboratories.

Equipment was integrated into the curriculum in the form of laboratory experiences in required courses in the Civil Engineering Technology program at Fairmont State College. Data acquisition equipment is interfaced with triaxial, hydraulic conductivity, direct shear, unconfined compression, and consolidation test equipment to facilitate data collection and reduction. The monitoring/logging instrument is interfaced to a 386 computer, equipped with the HOST® Management System developed by the Humboldt Manufacturing Company™, to provide user-specified monitoring for time-dependent laboratory exercises. Data is collected at user-selected intervals, and can thus provide overnight and weekend data collection.

Applicable Courses

Courses in which this equipment is utilized include three sequential courses beginning at the sophomore year. They include:

A) CIV 220 - Construction Materials and Methods (Sophomore)

B) CIV 340 - Soil Mechanics & Environmental Geotechnics (Junior)
C) CIV 470 - Advanced Soil Mechanics & Foundation Design (Senior)

Generally, the equipment and concepts are introduced and demonstrated in the construction materials and methods course. Students begin to use the equipment in the junior level soil mechanics course. An advanced treatment and use of the data acquisition equipment and software is required in the advanced soil mechanics segment of the senior course.

Experiments Utilizing Data Acquisition

Laboratory experiments where data acquisition is advantageous include direct shear, consolidation, hydraulic conductivity, triaxial shear, and unconfined compression. Laboratory procedures utilizing data acquisition can enhance the students' ability to integrate the theoretical into practice by allowing students to apply analytical skills to real applications while using modern instruments. Students are typically required to concurrently collect data manually while the data acquisition system is recording data; thus, a comparison of the accuracy of the data collection can easily be made. For purposes of this paper, the use of data acquisition for two tests will be discussed; namely, the direct shear test and the consolidation test.

<u>Direct Shear</u>

Head (1988) indicates that the direct shear test is the simplest, oldest and most straightforward method of determining the short-term shear strength of soils. The earliest known attempt to measure the shear strength of a soil was in 1846 by French engineer A. Collin. He attempted to perform a double shear test on clay using a split box 350 mm long by attaching hanging weights. Later, British engineer Bell (1915) constructed a shearbox and subsequently published results of a series of shear tests on various soils. In 1934, the Building Research Station, developed a stress-controlled single plane of shear apparatus whereby loads were added in an incremental fashion. A. Casagrande developed a shearbox at Harvard in 1932 that served as a prototype for what is the current state-of-practice device. In 1936, Gilboy developed a strain-controlled machine which provided for a constant rate of displacement through the use of a fixed speed motor drive.

This angle of friction test involves failing a soil across itself at a predetermined plane. A soil specimen is placed in a rigid metal box split into top and bottom halves. One half of the box is secured and stationary while the other half is moved relative to the stationary half by a motorized unit. A normal load is applied by a yoke and hanger assembly. The direct shear apparatus at FSC is a Wykeham-Farrance model WF25402 that provides for multiple size shearbox assemblies. Limits of the device allow for consolidation loads up to 10.0 kN (2200 lb) and maximum shear force up to 5.0 kN (1100 lb). The direct shear apparatus has a 2.5” diameter shear box and can apply shear force at speeds ranging from 0.00013 to 2.0 mm per minute. Direct shear tests are performed to meet specifications of standard test methods ASTM D-3080 and AASHTO T-236. A photo of a typical direct shear apparatus is included as Figure 1.

Figure 1. Photo of Typical Direct Shear Apparatus.

Data produced during this test include horizontal and vertical displacement and shearing force; hence computations for shear stress, normal stress, and strain can be performed. Normally three tests are performed on specimens of the same soil under different normal loads. This provides three normal stresses. Thus shear stress vs. displacement curves can be generated for each normal load. The peak shear stress can then be extracted from each of the shear stress/displacement curves and plotted against the corresponding normal stress, σ_n. This plot of normal stress v. peak sear stress generally approximates a straight line with an inclination to the horizontal acknowledged as the internal angle of friction, φ, and its intercept on the vertical axis representing the cohesion, c. The relationship between these parameters, known as the failure envelope, was first stated by Coulomb in 1773 as: $\tau_f = c_u + \sigma_n \tan\phi$

Use of the direct shear system allows undergraduate students to participate directly in determining shear strength parameters of various soils. Digital dial gages provide readings for horizontal displacement, vertical displacement and applied load. This test is a particularly good place to use data acquisition due to the fact that students must record three readings simultaneously. The test can be monitored through an elementary computer/data acquisition interface.

Raw data is collected via the data acquisition system which is controlled by the HOST® Management System. Data can be reduced manually or automatically using GEOSYSTEM® computer software developed by Von Gunten Engineering Software, Inc. Data can be collected and synthesized by the data acquisition system, or recorded and reduced manually, or both. The instructor may initially require students to collect data manually, and then compare results with automated report output produced with the Von Gunten Engineering Software from the data collected by the data acquisition system.

Consolidation Test Apparatus

Karl Terzaghi's 1925 "Erdbaumechanik" described the problem of long-term consolidation and proposed his now-famous theoretical treatment of the consolidation phenomena which he later published as a mathematical theory in 1936. Terzaghi designed and named the first consolidation apparatus an oedometer (from the Greek oidema, translated swelling). In 1938, Skempton of Imperial College developed an oedometer for a 1" thick specimen using a bicycle wheel to support the beam counterbalance weight. Nixon developed a compact oedometer for 3 inch diameter and ¾ inch high specimens in 1945. The consolidation (oedometer) test apparatus consists of a rigid loading frame, a fixed ring consolidometer, dial indicators and weight sets which provided a rated capacity of 48 tsf. Testing standards for this instrument include ASTM D-2435, D-4546, and AASHTO T-216. In the fixed ring oedometer, the soil specimen is located between porous discs above and below to allow drainage. The top disc is slightly smaller than the metal specimen ring containing the soil; this allows the top of the specimen to displace under loading. A photo of a typical oedometer is provided as Figure 2.

Figure 2. Photo of a Typical Oedometer.

Typically, a dial gage measuring vertical compression is manually observed on this apparatus by the student to be plotted as a function of log time; this may involve taking readings at very closely spaced time intervals at the beginning of the test. Use of data acquisition equipment greatly facilitates this process. Also, use of data acquisition is particularly beneficial for the consolidation apparatus due to the typical 24 hour cycle required for each load increment. The system is directed to take readings at specified time intervals overnight while students and faculty are home.

Data Acquisition & Control System

A Digitech™ data acquisition system is employed with this system. This system consists of a fully digital monitoring/logging instrument operating multiple channels for monitoring, and was interfaced with an existing 386 computer for continuous monitoring of tests. The data acquisition system is controlled by the HOST® Management System developed by the Humboldt Manufacturing Company™, to provide user-specified monitoring for time-dependent laboratory exercises. A photo of the computer and data acquisition system are presented as Figure 3A; Figure 3B provides a view of the screen as a direct shear test is about to begin.

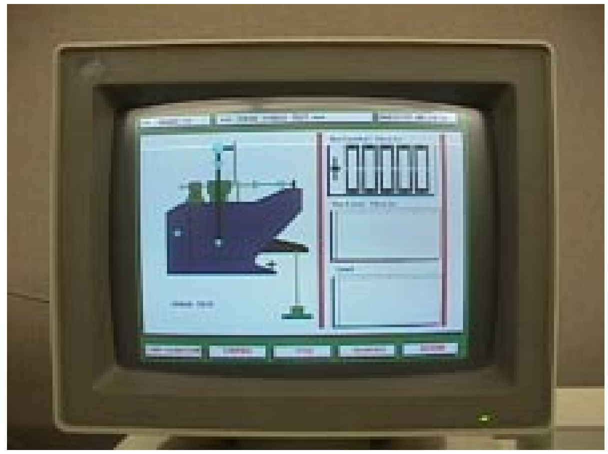

Figure 3. A) 386 Computer & Data Acquisition System B) Monitor Display of Direct Shear Test

Data is collected at user selected intervals, and can thus provide overnight and weekend data collection. Triaxial, consolidation, and permeability tests can require several days to complete, and a data acquisition system is advantageous for these experiments. One of the obvious benefits of the data acquisition system is time management; for instance, students can begin consolidation tests, collect data "through the night" and apply incremental loading the next morning while obtaining a full night’s sleep.

Data Reduction & Reporting System

Data can be reduced manually or automatically using GEOSYSTEM® computer software developed by Von Gunten Engineering Software, Inc. Programs are available for shear and consolidation. The GEOSYSTEM® SHEAR software provides capability to reduce data and generate reports for the direct shear, unconfined compression, and triaxial shear tests.

In the GEOSYSTEM® SHEAR software, each test may have up to 4 specimens. The software handles up to 100 readings for stress-strain calculations of each specimen. Calculations for initial, saturated, consolidated and final moisture are performed as are stress ratios for the major and minor principal stresses. Shear envelope, p-q diagrams, pore-pressure vs. Strain, and volumetric strain computations and plots are available. Reports can be generated that are industry standard, or meet Corps of Engineers requirements.

In the GEOSYSTEM® CONS (consolidation) software, both square root and log of time methods of data reduction are available. Coefficient of consolidation, void ratios, compression index, preconsolidation pressure, swell pressure, and swell/collapse percentage are calculated by the program. Typical graphs such as void ratio vs. Applied pressure, coefficient of consolidation vs. Applied pressure, and time vs. Dial readings using either square root or log of time.

Using these software packages, students can analyze test data for many soils in a rapid manner. This initiates the process of acquiring a comprehensive knowledge of regional soils and other materials.

Benefits to Students

Undergraduate students at Fairmont State College are afforded an opportunity to study the concepts of permeability, consolidation, direct shear, triaxial shear, and unconfined compression in a laboratory setting with data acquisition and automated reduction. These students get hands-on experience performing ASTM standard laboratory test procedures. Equally important, the students are required to analyze the test data and submit written reports on real soils from West Virginia as opposed to "textbook" soils.

Continuous monitoring and retrieval of data by the data acquisition system provides state-of-practice exposure for the students while allowing them to spend weekends analyzing results and studying concepts instead of collecting data. According to the students, this exposure to, and use of, state-of-practice testing equipment and data collection have enhanced the quality of education for the students. Skills are learned through hands-on experience that otherwise would not be obtained in the classroom; this typically results in a more thorough understanding of the practical aspects of these activities.

In summary, the use of data acquisition equipment allows students to obtain a more comprehensive undergraduate education through improved laboratory experiences. Not only is data acquisition useful in facilitation of expedient experimentation in an academic setting, knowledge of data acquisition is a marketable skill for CET students now and in the next century.

References:

American Society for Testing and Materials Part II, Test Designation D2435-70, 'One-dimensional consolidation, property of soils'. ASTM, Philadelphia, USA.

American Society for Testing and Materials (1979), Test Designation D 3080. 'Standard method for direct shear test of soils under consolidated drained conditions'. ASTM, Philadelphia, USA.

Bell, A. L. (1915). 'The lateral pressure and resistance of clay, and the supporting power of clay foundations'. *Proc. Inst. Civ. Eng.,* 199, 233-272.

Casagrande, A. (1932). ' The structure of clay and its importance in foundation engineering'. *J. Boston Soc. Civ. Eng.,* Vol.19.

Casagrande, A. (1936). ' The determination of the pre-consolidation load and its practical significance'. *Proc. 1st Int. Co. Soil Mech.*, Cambridge, Mass., Vol.3.

Collin, A. (1846). (Translated by W. R. Schriever 1956). Landslides in Clays. University of Toronto Press.

Cooling, L. F. and Skempton, A. W. (1941). Some experiments on the consolidation of clay'. *J. Int. Civ. Eng*., Vol. 16.

Cooling, L. F. and Smith, D. B. (1935). ' The shearing resistance of soils'. *Proc. 1st Int. Conf. Soil Mech. and Found. Eng*. 1936, Vol. 1.

Gilboy, G. (1936). 'Improved soil testing methods'. *Engineering News Record*, 21st May 1936.

Golder, H. Q. (1942). ' An apparatus for measuring the shear strength of soils', *Engineering*, 26th June 1942.

Head, K. H. (1982). 'Manual of Soil Laboratory Testing: Vol. 2: Permeability, Shear Strength and Compressibility Test'. Pentech Press, London.

Lambe, T. W. (1951). Soil testing for Engineers, Wiley, New York.

Skempton, A.W. (1944). 'Notes on compressibility of clays', *Q..J. Geol. Soc*., London. Vol. C.

Skempton, A.W. (1958). 'Arthur Langtry Bell (1874 – 1956) and his contribution to soil mechanics'. *Geotechnique*,Vol. No. 4.

Terzaghi, K. (1925). Erdbaumechanik auf bodenphysialischer Grundlage, Deuticke, Wien.

Tervaghi, K. and Frolich, O.K. (1936). Theorie der setzung von Tonschichten; eine Einfuhrung in die analytische Tonmechanik. Deuticke, Leipzig.

Terzaghi, K. and Peck, R. B. (1948). Soil Mechanics in engineering Practice, (2nd ed. 1967). Wiley, New York.

Von Gunten Engineering Software, Inc. 'Geosystem; Software for Triaxial Shear, Direct Shear and Unconfined Compression Test Calculation and Report Production', (1987), Fort Collins, Colorado.

Von Gunten Engineering Software, Inc. 'Geosystem; software for Consolidation Tests', (1986), Fort Collins, Colorado.

Wykeham Farrance Engineering Limited. 'Residual shear apparatus, BS1377:1990 Part 7 ASTM D 3080, Berkshire, England.

Biographical Information

ANTHONY L. BRIZENDINE is Director of the College Honors Program and Associate Professor & Coordinator of the Civil Engineering Technology Program at Fairmont State College. He is a Past-President and current Treasurer of the West Virginia ASCE Section, and was the first continuing education committee chair for the WV Section. He currently serves as the ASCE CTC&A Secretary. He holds a M.S.C.E. from Virginia Tech and a Ph.D. in Civil Engineering (geo-environmental) from West Virginia University. He is a licensed professional engineer and surveyor.