Application of Automation in Geotechnical Testing

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ABSTRACT: This paper presents the application of the latest technologies in electronics, software, automated controls to geotechnical testing. Geotechnical testing current state-of-the-art equipment, principle, and capabilities are also reviewed. The advantages and disadvantages of the use of fully automated soil testing are discussed based on experiences of a modern soil-rock-geosynthetics testing services laboratory. A particular emphasis is given to the time saving achieved by using fully automated computer-controlled testing system for performing triaxial and consolidation laboratory soil tests. An innovative feature that makes use of the Internet to remotely monitor and control a test is presented alongside some powerful software features to run advanced tests, and the latest technologies in load, displacement and pressure measurements. Current fully automated computer-controlled geotechnical testing systems use Proportional-Integral-Derivative (PID) adaptive controller technology to improve the quality of the test in terms of reliability, repeatability, accuracy, and confidence in test results, while reducing human error as well as end-user subjectivity. The internet remote control allows users the ability to adjust and edit test parameters, in real-time, while the test is running, in each phase of the test through the use of a Virtual Network Computing (VNC) software program. Operating these automated geotechnical systems in a VNC environment can substantially improve time management, efficiency, and cost-effectiveness of this equipment operation. Further benefits may be realized in the areas of training, remote-evaluation and diagnostics, and collaborative research.

Keywords: Soil Testing; Full Automation; Remote Control; Virtual Network Computing (VNC),

1. INTRODUCTION

Historically, geotechnical testing systems for the accurate determination of consolidation, permeability, modulus, and shear strength, have been relatively expensive, bulky, complex, and fairly labour-intensive to operate. Consequently, their use was typically limited to government, universities, advanced research centres, and agencies where the investment in both equipment and skilled operators was worthwhile. Nowadays there are still soils laboratories throughout the world using decades old technologies. The ever-growing need for electronic sensors in domestic and industrial applications has led to a mass-production market for load, displacement, and pressure sensors; these sensors constantly improving in performance while simultaneously becoming less expensive. The combined growth of sensors and test controllers with computer technology has resulted in the development of systems capable of simultaneously controlling several testing stations in real time, and performing some of the most sophisticated tests that closely. Test data recording, monitoring, control, processing, reporting, and archiving test files is now possible for a wide variety of geotechnical tests. Advances in geotechnical test equipment automation over the past 15 years now make it possible for complete computer control of most tests following the initial test set-up. Where traditional testing used manual dial gages, valves, switches, levers, static weights, and manometers, today's fully automated geotechnical testing equipment relies on the use of highly precise micro-stepper, servo-motors, servohydraulics, electronic valves and sensors, data acquisition and controls, and computer networking (Marr et al. 2003). Through internet connectivity and the application of Virtual Network Computing (VNC) (RealVNC Ltd.) it is now possible to observe tests and adjust test parameters remotely, from another workstation in the same laboratory, or from a laptop computer thousands of kilometres away.

2. REMOTE CONTROL

2.1 Introductory to VNC

Recent advances in internet technology have resulted in the emergence of software programs that allow users to view and fully interact with one computer from another computer anywhere on the internet by means of a VNC-type program. An 'open source' computer software version of VNC has been available since 1998. Communicating through VNC is independent of the computer operating system; a Linux® machine could remotely access a Microsoft Windows® PC. VNC-type programs are simple and widely used in diverse applications spanning different industries, private companies, and academic and government institutions. Figure 1shows a schematic diagram of a VNC environment where an outside user is able to communicate with a standard, networked, PC controlled geotechnical testing system.

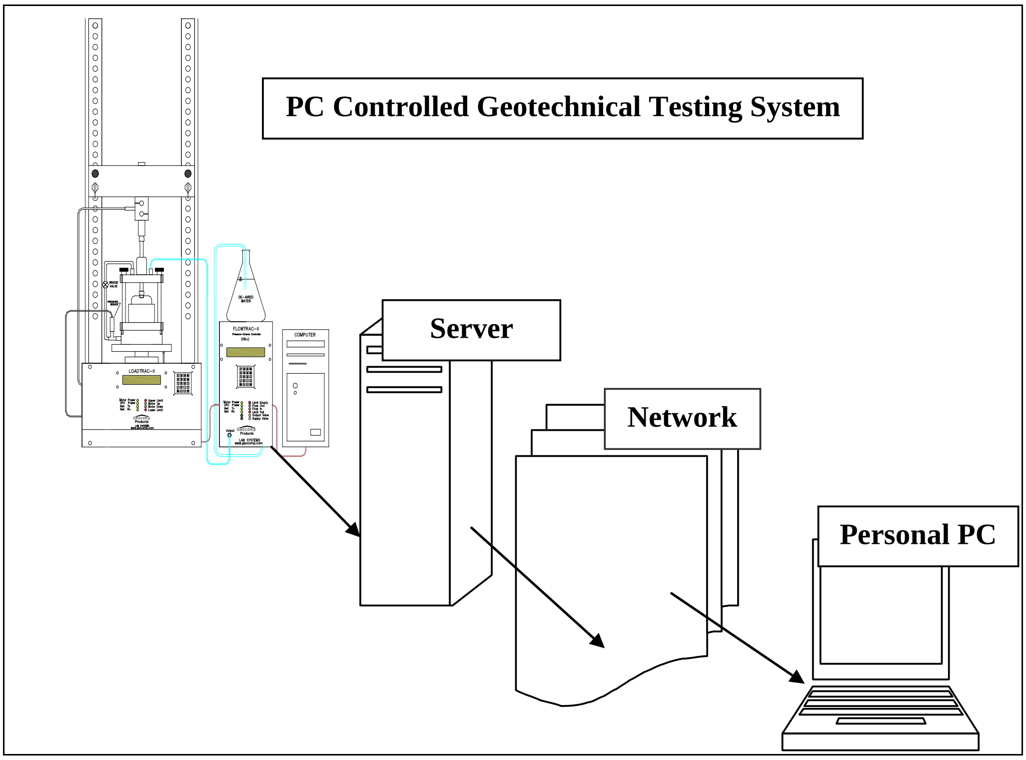

Figure 1. VNC enabled PC controlled geotechnical testing system diagram

The combination of VNC and computer controlled geotechnical testing equipment can provide a major advantage for geotechnical tests that are inherently time consuming, and may benefit from, or require, test parameters adjustments while the test is running. Such tests include consolidation, triaxial, and direct shear. The shear rate of a triaxial or direct shear test, based on the consolidation phase results, may require adjustment during a test for improved test quality and to meet test standards requirement.

Likewise, an incremental consolidation test may require the loading and unloading sequence to be altered to better define and capture the maximum past pressure information.

VNC eliminates need for the user to be physically present at the testing station to make these adjustments when required. Adjustments as well as other controls (test abort and test restart for example) and additional interaction can now be performed using a remote computer connected to the internet with a properly configured VNC system. The system can also be used to allow real-time test observation and interaction from distant workstations or from remote locations as part of distance education programs, off-site tech-support, or other collaborative efforts. The VNC enterprise software system also has security features to ensure that networks are not compromised by unauthorized users.

2.2 VNC Set-Up

To remotely monitor or control fully automated tests by using a VNC application the user will need to have active internet connections for both the test control computer and the remote computer. The VNC software must be installed and running on both the computer operating the test and on the remote computer. In addition, the Internet Protocol (IP) address or domain name server (DNS) entry of the test workstation computer is necessary for the VNC software to make a connection with the local system.

The VNC software defines the workstation to be interacted with as the 'server' and the computer doing the interacting at-a-distance as the 'viewer.' Note that is a condensed description of the basic operations of the system; there is some amount of set-up required with the VNC free-ware and there may be complications depending on particular internet related configurations (fire-walls, proxy servers, and dynamic IP addressing). Further details are available at www.realvnc.com.

Once VNC is properly configured on both the local test control workstation and on the remote computer, when the user starts the VNC program on the remote computer a dialogue window will open and the software will prompt the user to log-in. The user can then enter the computer IP address or DNS entry and the associated password for the VNC session for the PC running the test (this password is assignable when the VNC software is loaded on the 'server' computer) as shown in Figure 2. Once logged-in, the user has full control of the PC, and the test, just as one would as at the local PC.

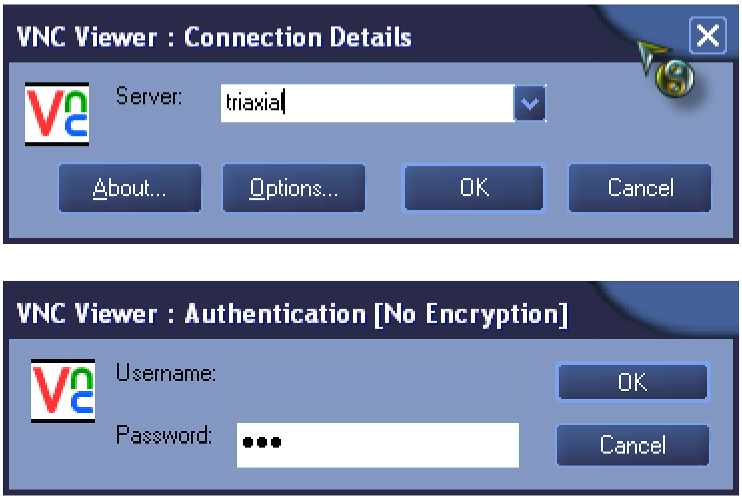

Figure 2. VNC 'viewer' dialogue boxes, prompting the user to establish a connection with the VNC 'server' which could be any one of a number of test control workstations.

2.3 Advantages of VNC as Applied to a Fully Automated Triaxial Stress Path Test

A popular and common triaxial test such as a consolidated isotropically undrained compression (CIUC) test is comprised of at least three test phases, usually with several steps within a given phase. Figure 3 shows a collection of real-time test screen-captures displaying backpressure saturation, consolidation, and shear phases plots. Generally, most tests are monitored from a local workstation which may provide test control and monitoring for one or more simultaneous tests on multiple pieces of automated equipment.

Triaxial Stress Path tests can be designed to model a wide variety of anticipated field loading, unloading, and pore water pressure changes (Dasenbrock and Hankour 2006). Tests parameters can be set to permit changes in both horizontal and vertical stress and sample pore pressure. Although the test can proceed without operator intervention, as the test may take several days to progress, by using VNC, the test operation can be checked remotely, by lab technicians, project engineers, lab supervisors, expert consultants, students, or other project collaborators who may wish to be involved in either observing or directing the test.

Changes to the testing routine can be incorporated at-a-distance by authorized users. Saturation, consolidation, or shear rates or target values may be changed, as well as any other parameter that could be adjusted locally.

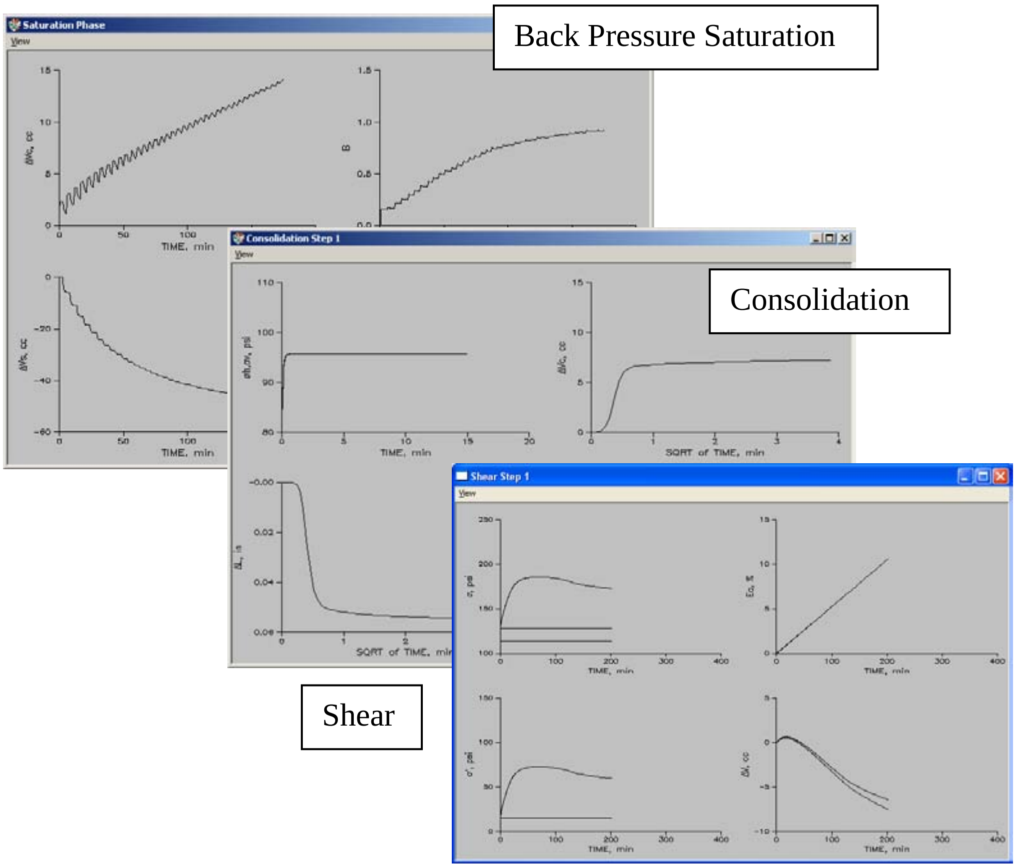

Figure 3. Real time display of a typical sequence of the phases of a CIUC triaxial test: back pressure saturation, consolidation, and shear

3. MEASUREMENTS IN LABORATORY SOIL TESTING

3.1 Volumes and Pressures

Currently in the majority of soil testing laboratories manual panels with air pressure supply and pressure regulators are used to apply pressure through a pressure regulator, and read volumes of graduated burettes. This is method is prone to operator subjectivity, not very accurate and time consuming. Figure 4 shows a typical manual set-up for pressure application and volume measurements.

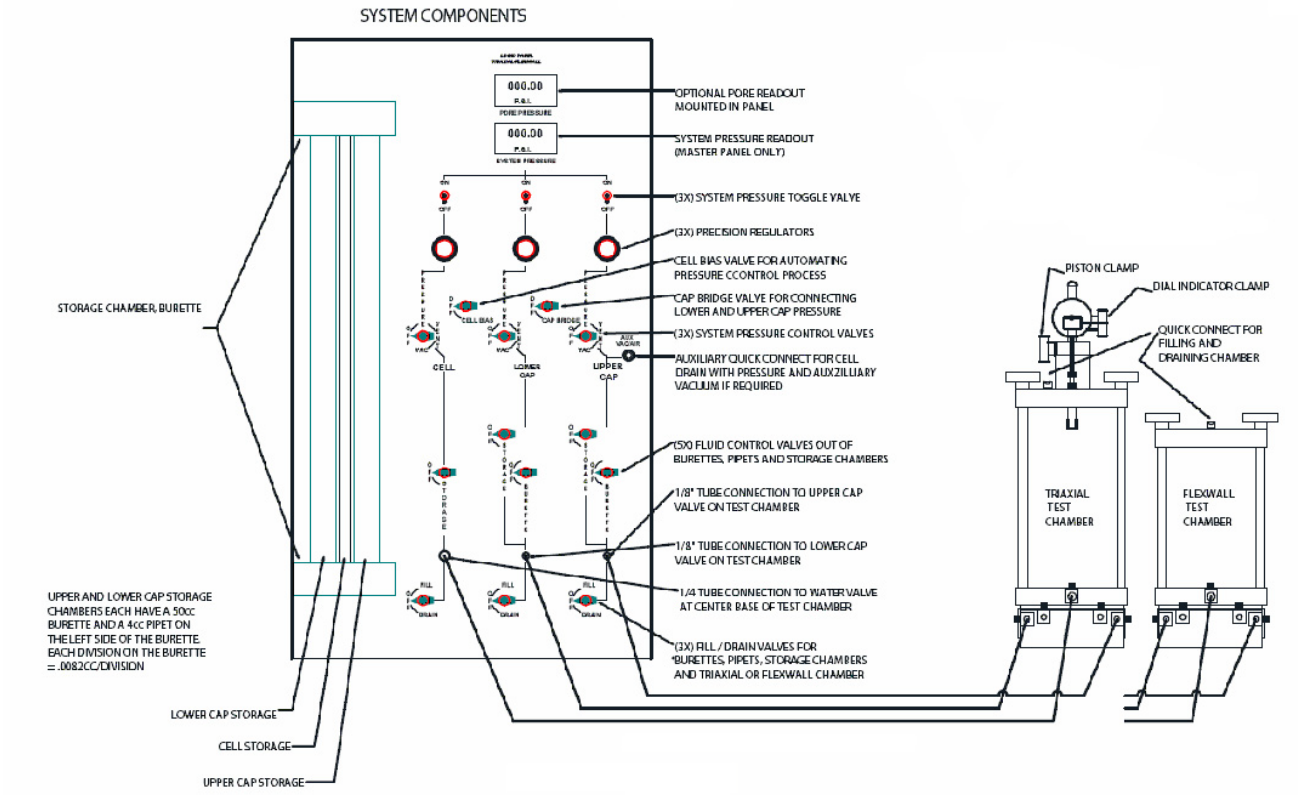

Figure 4. A typical manual pressure volume controller to run flexible wall permeability and back pressure saturation and consolidation phases of a triaxial test

The first application of medical flow pump was reported in 1988 (Menzies 1988). Nowadays typical geotechnical flow pumps consist of a precision assembly where a piston actuator maintains or adjusts either pressure or volume parameters. A pressure transducer is used to monitor the system pressure where the deflection of the piston is used to determine changes in system volume. Although, there are several types available commercially, most of the basic operating principles among these systems remain the same, including the use of closed-loop control processes with electronic sensors providing system feedback for computer monitoring and control adjustments. Two two-way electronic valves are used to control the direction of flow to the cell or sample (output valve), and the manual fill/drain operation (supply valve). A standard flow pump is now capable of applying and maintaining the desired pressure within 0.35 kPa (0.05 psi) while monitoring volume changes within 0.001 ml, and flow rates can be set to any value between 0.000006 ml/sec. and 3.0 ml/sec. Figure 5 shows a schematic diagram of a modern flow pump.

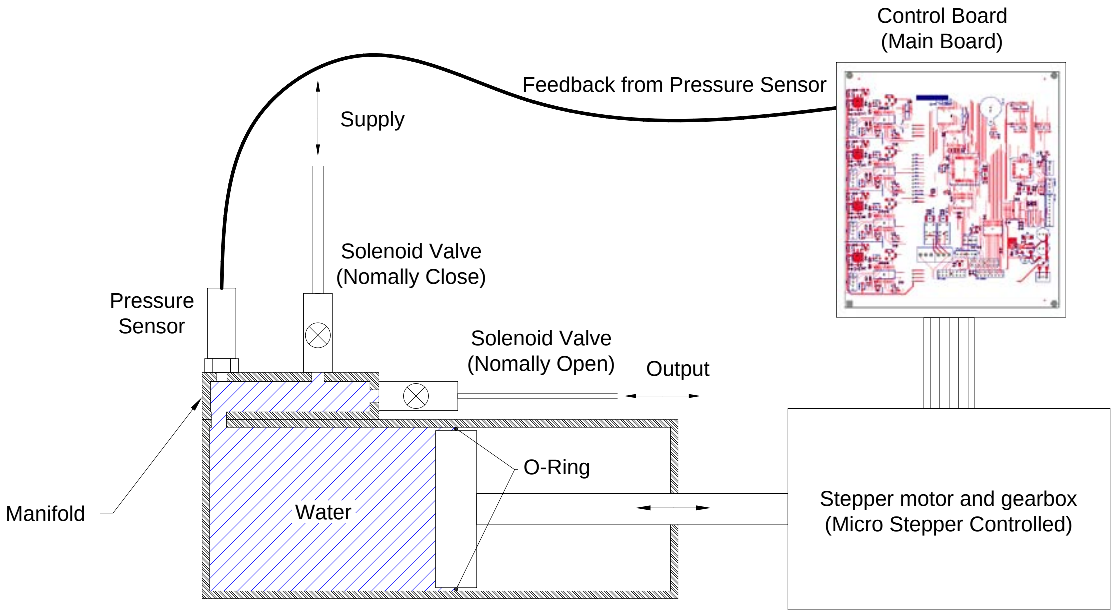

Figure 5. Diagram of a fully automated flow pump

3.2 Loads

Newer load cells are universal which work equally in both tension and compression, they are typically environmentally sealed, with a total combined error of less than 0.02% of full scale. Because of the powerful computing features of the control software combined with a minimum triaxial cell piston friction due to better linear bushing and O-ring sealing, the use of internal load cells is no longer necessary. The triaxial software program code is now capable to eliminates the need of a submersible load cell due to its advanced computing power and feed-back control that takes into effect the following forces when it tries to apply the vertical stress during the close loop control; axial load (+), uplift force due to the confining (cell) pressure (-), weight of the piston (+) and piston friction (-). Furthermore external load cells present several advantages over the internal ones, such as their robustness, better performance, interchangeability and extreme ease to set-up. More importantly external load cells cost a fraction of their submersible counterparts due to their mass production and numerous uses and applications.

3.3 Displacements

Until recently the widely used sensors which most major testing standards recommend for deformation measurements were LVDT's (Linear Variable Differential Transformer). However there have been new position sensors that employ conductive-plastic resistance and collector tracks that provide direct means of measuring position, without the need of a solid mechanical coupling. These new displacement sensors have better technical specifications at comp lower price. Some specifications of the latest displacement sensors are as follow:

- Long life – 100 x 10^6 movements
- Outstanding linearity – up to ±0.075%
- Repeatability= 0.002 mm
- Double bearing system on shaft insensitive to shock and vibration
- Spring loaded
- Price comparable or even less than LVDT's for 10 times superior performance

4. FULLY AUTOMATED COMPUTER-CONTROLLED GEOTECHNICAL TESTING SYSTEMS

4.1 Introductory to automated computer-controlled systems

There are several varieties of geotechnical testing equipment on the market that range from very basic manual systems with hand cranks and dial gages to fully automated systems with advanced electronic sensors and computer test control. This paper focuses on the fully automated geotechnical testing systems allowing test control in addition to, more typical, test data acquisition and reporting (Marr et al. 1998) and (Dasenbrock et al. 2005). By definition, these systems are computer-controlled where the test automatically progresses from one phase, or step within a phase, to another based on the test criteria set by the user not to be confused with a manual system such as a dead weight oedometer with a displacement sensor connected to a data acquisition resulting in the automation of the data collection only.

As shown in Figure 6, a fully automated triaxial system typically consists of a load frame for applying and controlling vertical stress and strain, and two flow pumps for applying and controlling cell and sample volume and pressure, and a computer with a network communication card for test control and data acquisition processes. Each piece of test equipment is hooked to another unit, or the local test control computer, as nodes in series in a 'daisy chain' network arrangement.

The testing hardware is somewhat different from traditional devices that used weights, cranks, manometers, and various mechanical and hydraulic control systems to apply loads and pressures. A typical loading mechanism uses a high speed, precision micro stepper motor controlled through an onboard dedicated embedded controller with a central processing unit (CPU). Force is measured by a load cell; a displacement sensor is used to measure deflection.

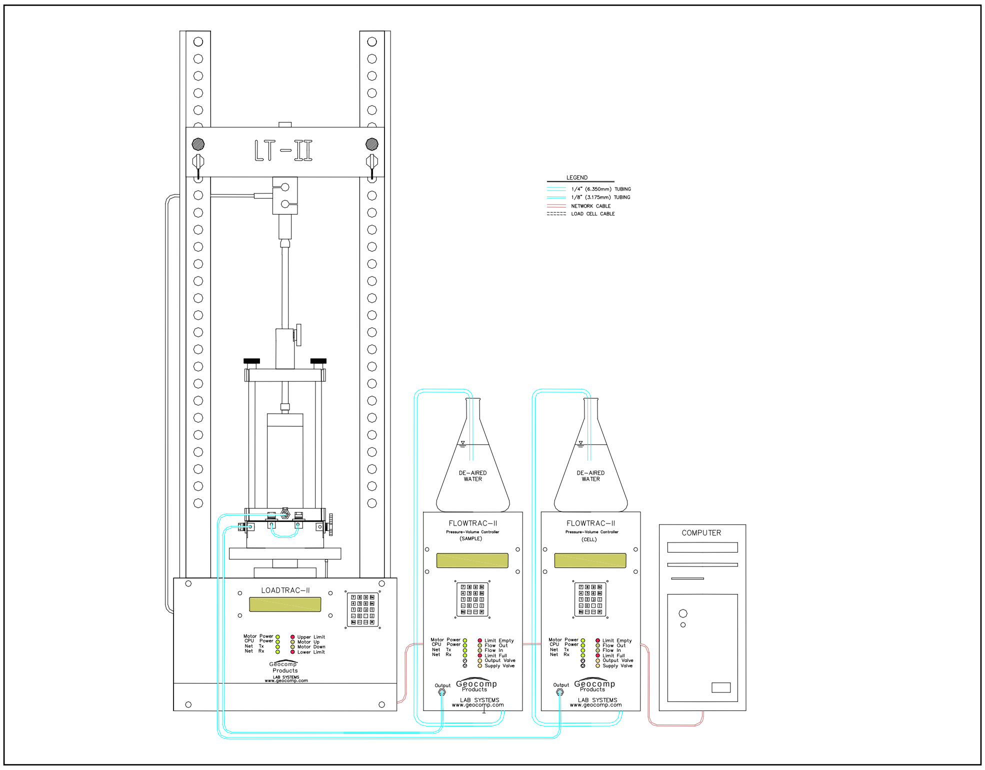

Figure 6. Front view of a fully automated triaxial and stress path system

4.2 Advantages and disadvantages of fully automated systems

A major advantage is the substantial reduction in both labour and testing time required to run some triaxial and consolidation tests as shown in Table 1, and Table 2. Other advantages are listed as follows:

- Reduce risk by improved and reliable test data
- Maintain and manage information flow
- Finish tests faster
- Provide consistency in test procedures and results
- Give more data on all phases of test
- Permit more detailed analysis of test
- Make more specialized tests possible
- Utilize facilities better
- Improve quality
- Present data to meet specific client needs
- Electronically submit results
- Make lab work more interesting for the technician
- Improve image of lab to clients
- Save money by running several testing stations from one PC

The disadvantages are listed below:

- Automated equipment tends to have higher up front cost
- Automation generally requires a higher knowledge level from the end user
- The above can produce efficiency problems in commercial labs if staff turnover is high
- Calibrations of sensors should be performed more frequently
- Power brownout or blackouts can cause severe damage and loss of tests results
- Over-reliance on PC, and tendency to forget to observe key parts of the test and examine test results carefully

Table 1. Labor saved with fully automated consolidation testing

Soil Type	**Test Time, days**			**Labor, hours**		
	Conventional	Automated	Testing Time Saving	Conventional	Automated	Labor Saving
Silty sand	16 ~18	0.5 ~ 1	94% ~ 97%	4 ~ 12	1	75% ~ 92%
Silty Clay	16 ~18	1 ~ 2	88% ~ 94%	8 ~ 16	1	88% ~ 94%
Plastic Clay	16 ~18	2 ~ 3	81% ~ 89%	12 ~ 32	1	92% ~ 97%

Includes 12 load steps with one log cycle of secondary compression. Times include preparing specimen, running test and reporting results. Times for conventional tests assume standard practice of applying each increment for 24 hrs.

Table 2. Labor saved with fully automated triaxial testing

Soil Type	**Test Time, days**			**Labor, hours**		
	Conventional	Automated	Testing Time Saving	Conventional	Automated	Labor Saving
Silty sand	1	0.5	50%	6 ~ 8	2	67% ~ 75%
Silty Clay	2	1	50%	10 ~16	2	80% ~ 88%
Plastic Clay	5	2	60%	12 ~ 24	2	83% ~ 92%

Times include preparing specimen, running test and reporting results.

4.3 Application of VNC to a private laboratory with fully automated equipment

It has been almost ten years that the VNC software was installed on several fully automated workstations at a private laboratory (www.geotest.com) in Massachusetts, USA. The system is used by the geotechnical lab engineers to monitor and when necessary change test parameter from home in the evenings and over the weekends. The system has also been used to display real-time testing information to off-site colleagues and to monitor tests in the lab from offices in another part of the building. While testing will continue to be monitored and controlled locally, the VNC software provides the ability to monitor and control test function in real-time, from any internet computer, and allow even for test adjustments at-a-distance.

5. CONCLUSIONS

Fully automated computer-controlled geotechnical testing systems are now available for a number of geotechnical tests. They are of modular design which allows creation of a testing station with many different test capabilities on one system. Common Windows user interfaces for different test modules let end users easily move from one test to another. Full automated provides a powerful tool for research and advanced studies. An addition benefit of the test automation is remote internet monitoring and test control. Observing and adjusting geotechnical tests remotely can improve test management, efficiency, and cost-effectiveness. Further benefits may be realized in the areas of training, distance education, remote diagnostics and assistance, and collaborative research and real-time test evaluation. With the advent of the fully automation the laboratory test is now capable of duplicating the field conditions assumed in the design as closely as possible (Dasenbrock and Hankour 2006).

6. ACKNOWLEDGMENTS

The author would like to thank Dr. Allen Marr the president of Geocomp for proving valuable resources for write-up of this paper. Acknowledgments are extended to Mr. Derrick D. Dasenbrock of Minnesota Department of Transportation and Dr. Da Ha of Geocomp Corporation for their help in the preparation of this manuscript.

7. REFERENCES

Dasenbrock D. D., Marr W. A., and Hankour R., 2005. Application of Automated Laboratory Tests to Minnesota D.O.T. Highway Project Site Characterization. Geo-Frontiers 2005, Austin, TX.

Dasenbrock D. D. and Hankour R., 2006. Improved Soil Property Classification Through Automated Triaxial Stress Path Testing. GeoCongress 2006, Atlanta, GA.

Marr, W.A. Torosian, G.T., and Hankour, R., Experiences with automated geotechnical testing, 1998. Non-Destructive and Automated Testing for Soil and Rock Properties, ASTM STP 1350, W.A. Marr and C.E. Fairhurst, Eds., ASTM, 1998.

Marr, W. A., Hankour, R., and Werden, S. K., 2003. A fully automated computer controlled resilient modulus testing system, Resilient Modulus Testing for Pavement Components, ASTM STP 1437, ASTM International, West Conshohocken, PA, 2003.

Menzies, B. K., 1988. A computer controlled hydraulic triaxial testing system. Advanced Triaxial Testing of Soil and Rock, ASTM STP 977. American Society for Testing and Materials, Philadelphia, 1988, pp. 82-94.

RealVNC Ltd., 17d Sturton Street, Cambridge CB1 2SN United Kingdom. http://www.realvnc.com (Aug. 31, 2005).