EFFECTIVE APPLICATION OF MICROCOMPUTERS TO GEOTECHNICAL ANALYSIS/DESIGN

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Computers in Lab and Field Data Applications

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The microcomputer has provided the largest single step forward in geotechnical testing since the development of reliable equipment for strength and compressibility testing. While some organizations used mainframes and mini computers in geotechnical laboratories, the inconvenience of working with punched cards, paper tape or magnetic tape and the expense of hardware, software and maintenance limited the usefulness of computers for day to day testing to a few large organizations.

In the late 60s MIT expended considerable effort to put the entire geotechnical laboratory onto a central data acquisition that used a minicomputer. After spending in excess of $100,000 for hardware, software development and installation, the system required $1,000 to $3,000 per month in hardware maintenance costs alone. Even with such costs, this system merely printed on a console readings taken at a constant time interval and wrote them onto a magnetic tape for processing on the mainframe a week later.

The microcomputer and associated developments in peripheral devices has radically altered this picture. Today, microcomputers graph reduced test results while the test continues to run. Report quality tables and figures are available within minutes of completing a test. Entire laboratories are monitored with hardware that occupies a small part of a desk top and costs a few thousand dollars. Some of the newest equipment uses microprocessors to control entire tests from start to finish. This has lead to substantial decreases in the man time required to perform tests as illustrated in Graph 1 for a typical incremental consolidation test.

Entire new types of tests are practical today that were only research tools or good ideas a few years ago. For example a single piece of equipment driven by a microprocessor like that shown in the accompanying photo can perform consolidation tests using incremental steps, constant rate of strain, constant rate of loading, constant gradient, etc. New equipment can perform a permeability test using the constant flow volume method in a few hours instead of several days required by conventional methods.

Most impressive but often overlooked is the large increase in reliability of the computer. Those familiar with computers in the 60's remember that a computer failure of some type was always imminent at any time. For years, user's of early data acquisition systems continued to take manual readings to cover the frequent failures of the system. Today a $1,000 personal computer may run for years without experiencing a single failure that results in lost data.

Improvements in programming tools and software make it much easier for more people to adapt the microcomputer to specific applications like analyzing geotechnical test data. For example many people with little knowledge of a programming language can set up a spread sheet to perform the required calculations for transforming test data to engineering quantities.

Benefits from this electronics revolution have been many to the modern laboratory. These include:

- faster completion of tests
- reduce labor required to collect and process data
- more data collected allowing more detailed examination of results
- more detailed data collected and analyzed more completely
- faster production of test reports
- better quality control over data collection and reduction
- improved test quality
- reduction of much of tedium in lab testing
- some tests made economically practical

Perhaps the largest influence of computers in field work has been in surveying and position monitoring. Electronics has radically improved our ability to obtain accurate and detailed surface positioning for less cost. However the geotechnical engineer is usually peripheral to this benefit so let's look at a few things of more direct interest.

Today we can connect instruments to a data logger containing a microprocessor that automatically reads each sensor and stores the data. We can hook it to a telephone and with another personal computer examine data from anywhere in the world. Such systems allow much more detailed monitoring of performance. Deviations in measurements that used to be attributed to measurement error may with more complete data now reveal useful information about performance of the site.

Virtually any field measurement can be made by computer. Unfortunately considerable money may still be required for certain instruments and installation of instrumentation. While the cost of computers has dropped dramatically and the cost of instrumentation has dropped a little, the cost of instrument installation has increased and remains the largest expense in field applications.

Computers allow us to perform much more detailed studies of field performance by permitting us to monitor more points and record data much more frequently. On a project in Boston, we are currently assisting to monitor 450 separate sensors several times a day for a duration of at least one year. The large number of instruments allows us to look at distributions of stresses and strains as well as provide redundancy and independent measurements. The frequent measurements allow us to follow each step of the construction in detail and remove environmental effects from the data. The duration of measurements allows examination of each construction stage on the stress-strain distribution within the slab. We hope to obtain sufficient data to determine the accuracy of our methods for designing thick mats on compressible foundations. The cost of reading this many instruments with such detail and for such a period would have been totally prohibitive a few years ago. Another system we installed in Japan in 1984 allowed us to monitor the performance of a dewatering system in great detail from 12,000 miles away. Unfortunately the computer in this system recently failed after 6 years of exposure to salt air.

Having been involved in literally hundreds of installations of microcomputer systems and software, I have noted some reoccurring problems and issues. Among these are:

1. Failure to recognize the need for training and time to learn a new system. Some managers seem to expect that "user friendly" means immediate results even when the user has never touched a computer.

2. Difficulty convincing some engineers of the monetary value of software. Many think that software comes for free. Many think they can buy a few parts and assemble an automated testing system in a matter of days. In fact automated testing systems require a lot of attention to system integration requiring detailed knowledge of hardware electronics, instrumentation, electrical noise control, computer hardware, computer software, geotechnical principles and testing practice. I know of no individual with mastery of all these areas and very few organizations with staff covering all these areas.

3. Tendency in our profession to do everything ourselves. As engineers, we seem to pride ourselves in our ability to figure anything out on our own. This can lead to expensive and less than desirable results when applied to computer systems. Many field data acquisition systems have failed for reasons that could have been avoided. Many have produced lots of data that was never effectively used because the budget was consumed trying to get the system to work or the requirements for an efficient data management system were never recognized.

4. Decline in the use of the laboratory and field measurements in engineering. Usually blamed on project budget pressures, declining use has made investment in new facilities and people difficult to justify.

5. Decline in use of specialty consultant teams on projects. Today an organization gets a project that may benefit from new or refined computer systems to carry

out that job. Chances are high that this organization will pull together an in-house team to carry off that project rather than seek out an external group to assist them who may have more expertise and experience in computer applications. After a lot of wasted effort, the project will be completed and the team will dismantle to do something else. The lessons learned and technology developed are lost. As a result, no company can develop a critical mass of experienced professionals to really apply this new technology to our professional needs for effective geotechnical data collection and management.

With all of this great technological capability, one might think it is a time for jubilation among those of us involved in developing new ways to use this technology. As one such person involved in the development of software for over 20 years, this is not the case. Products and system available today, while impressive, hardly begin to employ the total capability provided by today's hardware. The state-of-art automated test systems produced by GEOCOMP, acknowledged by many to be leading edge systems, are just getting to the point that they benefit from an AT class personal computer. Our applications are two to three generations behind what the hardware people are delivering. While the power of the hardware grows exponentially with the cost steadily decreasing, the cost of software and system development goes up. As customers expect and demand easier-to-use systems with more capabilities, the software behind those systems grows more complex and difficult. Software development tools have greatly increased the productivity of programmers over the days of punched cards, but the effort required to include features expected of any software product have outpaced such productivity gains. The United States market place has not been able or willing to pay the product price required to foster a healthy geotechnical software industry. Hopefully as more of our profession recognizes some of the hindrances that limit the effective use of these technological tools, new opportunities will develop to overcome these hindrances.

USE OF MICROCOMPUTERS IN GEOTECHNICAL LABORATORIES

The purpose of this paper is to give an overview of the present capabilities of microcomputer based data acquisition systems for geotechnical laboratories. My intent is to provide some perspective on typical system capabilities, issues involved in selecting a microcomputer-based system, and advantages and disadvantages of such systems. The examples I include are chosen for illustration. References to manufacturers and users are for illustration. By no means does this presentation give an exhaustive description of data acquisition hardware available today.

HISTORY

To my knowledge, one of the first data acquisition systems using a small dedicated computer was designed and installed in geotechnical laboratory at MIT in 1967. This system was based on an Hewlett Packard model 2114A computer, a digital volt meter, a scanner and a magnetic tape recorder. The original system cost approximately $30,000, took one man year to program, required a maintenance and service cost of approximately $3,000 per year and had an availability of around 70%. This system had the capability of accepting up to 200 channels of input with a scan rate of approximately 1 channel every 2 seconds. The original plan included provisions for receiving data from nearby field instruments via telephone line but this plan was never realized.

By 1973 this system was obsolete. A new line of data loggers appeared which offered many of the same features at a much lower cost. Typical of these systems was the Fluke model 2240A. This unit cost about $5000, could record up to 60 channels, at up to 15 channels per second and required no scheduled maintenance. Readings were printed on a built in printer. By adding a $3000 magnetic tape unit one could store readings for subsequent reduction by computer. It also had built in features to allow the user to pre-program some data acquisition tasks. This feature significantly reduced the cost of programming required by earlier systems. Today data loggers continue to provide a low cost means of collecting data in laboratories.

The introduction of the microcomputer and associated developments in electronics presented unlimited possibilities for automating data collection. For the first time, truly automated data collection and reduction became available to geotechnical laboratories at an affordable cost. The large number of different microcomputers has provided a variety of data acquisition systems installed in laboratories around the US. In a survey in 1985 by the Data Automation Task Force of Committee 18 of the American Society of Testing Materials, of 60 respondents over 1/2 were using a data acquisition system in their lab. A large majority of these were based on a microcomputer. The other notable point was that no two systems were alike. No one combination of equipment dominated.

TYPICAL SYSTEM COMPONENTS AND THEIR FUNCTIONS

Figure 1 illustrates the components of a complete data acquisition system. Each of these components can be provided by a separate electronic unit or various components may be combined into a single unit.

The sensor measures some quantity and converts that quantity to an electrical signal. Sensors exist to measure temperature, pressure, flow, strain, displacement, and force. Most sensors give a change in resistance, a change in output voltage, or a change in output current which is proportional to a change in the phenomenon being measured.

The isolation component electrically isolates the process being measured from the measuring equipment. Typically, the isolation component protects the analog to digital conversion equipment from accidental overloads of up to one thousand volts.

Signal conditioning depends upon the characteristics of the sensor and those of the data acquisition system. A signal conditioner may perform one or more of several functions including amplification, filtering, input protection, isolation, common mode rejection, and in some cases excitation of the sensor. It is common to buy signal conditioning in modules with each module conditioning one channel. Recent miniaturization of amplifiers now allows signal conditioning to be done within the sensor. Some manufacturers are beginning to provide this on board signal conditioning at very attractive prices. Most designers today if using a signal conditioner are seeking to obtain an output signal that conforms to a standard voltage range for data acquisition that is 0 to +10 volts d.c. output or 4 to 20 milliamps output. Some signal conditioners can additionally perform linearization and scaling of the sensor output.

The analog to digital converter must convert the analog signal in the form of voltage or a current to digital form that can be used by the computer. The converter usually dictates the overall capabilities of a data acquisition system. Characteristics of the converter control accuracy of the reading, the speed of the reading, the resolution and the cost.

The microcomputer must be capable of interfacing with the A to D converter and have a processing speed compatible with your data acquisition needs. It collects the digital signals provided by the A to D converter. In some applications it instructs the A to D converter on what and when to read, stores data for later use, performs any real time data reduction required, and sets up the information to be sent to a printer monitor or plotter.

To the microcomputer one may add any of the variety of peripherals or perform any of the numerous tasks done in other applications such as transmitting data to other locations, performing real time data reduction and plotting, presenting data to the screen for constant monitoring, or potentially sending signals back to the experiment to control the experiment. This last function involves essentially a reverse of the steps listed above. Some A to D units give a digital to analog capability that can be used for control of the test.

Control of testing is not treated here. It is a relatively new area in terms low cost capabilities but one that offers very exciting possibilities for the near future.

SOME TYPICAL SYSTEMS PRESENTLY AVAILABLE

Table 1 lists several systems presently available for data acquisition in geotechnical laboratories. Other manufacturers could be added to this list. I've chosen ones to illustrate the typical systems available. Also included in the list are typical costs.

The systems from Wykeham Farrence and GEOCOMP offer software specific to geotechnical data acquisition and reduction. This software acquires data on triaxial and consolidation tests, performs data reduction, and prints and plots reduced output. Tables 2 through 5 and Figures 2 through 4 reproduce typical output from these systems. With a suitable printer and plotter, one can obtain high quality output suitable for immediate inclusion into a report.

Many of the board level and stand alone systems come with limited software to acquire data. The user must add all software for storing, reducing, printing and plotting data. This software becomes quite involved if more than one test is run at a time.

SOME ADVANTAGES AND DISADVANTAGES OF AUTOMATED DATA ACQUISITION

Table 6 lists some of the benefits of a microcomputer based data acquisition system. Low cost storage allows one to collect and maintain a large quantity of data. A typical diskette can store up to 100,000 readings. A hard disk can store 30 to 1000 times this amount. Low cost, high speed data collection recently has become available as well. Sampling rates of 50,000 to 150,000 samples per second are now possible at one-third of the hardware cost three years ago. This capability allows one to monitor dynamic tests using a microcomputer based system.

The microcomputer operates uninterrupted 24 hours a day, 7 days a week, provided there is no loss of power. Some systems provide a back up to cover the loss of power should that protection be important.

One can accommodate many different tests. Through software, one sets up the data acquisition requirements for each type of test and stores the data in the most convenient form. The microcomputer may then do the data reduction making any necessary corrections and produce reduced data in appropriate engineering units. New systems allow data to be taken at different rates for each test so that now a system may be monitoring many different types of test with each test having its own conditions. For most static tests in the geotechnical laboratory, much of the data reduction can be done as the test progresses should that be desired. Another approach is to collect the data, store it and after the test is completed perform data reduction. However, this does not require any inputting the data again.

One can obtain a real time display of what is being measured or what has been measured. The feasibility of doing real time displays depends greatly on the rate of which you are taking samples and the processing speed of the microcomputer. With a 16 bit processor and carefully written and compiled software, it is feasible to plot stress paths or stress strain curves for dynamic tests loaded as fast as 5 hertz.

The microcomputer allows one to report data in any format they choose. If you write your own software, you can customize a report produced on the printer to meet the needs of your company. Several of the commercially available packages provided printed reports with some customization to your own needs. One can also obtain plots of reduced data. Low cost pen plotters allow very high quality color plots to be produced at relatively low cost. Laser printers provide high quality output and are highly reliable.

Once a system is operational, the microcomputer greatly decreases the chance for human error. Standard calculations are performed over and over again. Once the code has been completely debugged and checked, you have the confidence that data reduction is being performed accurately every time. Automated data acquisition systems can reduce labor costs. This is particularly true where you have a high testing volume and are running tests that require a large amount of data reduction and plotting. Labor time is reduced for collecting data, reducing data, plotting data and checking. With planning, overtime can be essentially removed. For laboratories where high quality printed reports and plots are desired, we have estimated the potential savings form a complete microcomputer base data acquisition system: for a consolidated triaxial test with pore pressure measurements up to 16 man hours, for an odometer test with at least one unload-reload cycle up to 20 man hours and for a UU test up to 2 man hours.

Automated data acquisition systems allow one to achieve greater repeatability of test conditions. By providing real time data reduction, the technician can obtain exactly the initial starting conditions required by the test program. Future developments in test control using the microcomputer will greatly enhance our ability to produce any desired test condition and repeat that condition.

The microcomputer based data acquisition system offers interesting possibilities for maintaining data bases of test data over long periods of time. This potentially offers the engineer the chance to get better use of data and take advantage of previous testing in a given area. Unfortunately, considerable effort is required to set up a useful data base management system to handle the enormous quantities of data produced in laboratory environment.

Table 7 lists some of the disadvantages of computer based data acquisition systems. With the decreasing costs of the electronics, one of the more expensive items has become the costs of the sensors. A typical LVDT for measuring displacement costs around $300 including mounting hardware. A pressure transducer may cost $300.

An accurate load cell with mounting equipment may cost up to $500. Therefore the cost of automating a triaxial test may be $1100 per set up in sensor costs alone. Odometer tests require only 1 LVDT; consequently sensor costs are less of a problem.

The second expense is the cost of the software to have the system perform its desired functions. The market for geotechnical software is relatively limited so that the full economies of scale can not be realized. Some commercial producers of geotechnical software do exist sand data collection and reduction software packages are now available. This approach usually provides software for a lower cost than in-house development but has the disadvantages of making you dependent on the software developer and giving report formats which are relatively standardized. An alternative is to write your own software. At face value this appears attractive to many firms. It has a hidden trap. It is very expensive. Software industry statistics show that it takes approximately $20 per statement to write, develop and test computer software. For a program to reduce and print out UU test data, this translates to approximately $2000 in software development cost. For a program to reduce, print and plot results from triaxial tests, this translates to a cost of as much as $30,000. Our GEOLOG IV system required approximately one man year of development time.

Automatic data acquisition systems generally require higher technical skills on the part of the user than do manual readings. The user must be able to input commands on the keyboard. Additionally, the user must have some familiarity with mounting sensors and diagnosing problems with the sensors. The user also should have some general familiarity with how the measuring system works.

If a system fails, one may lose data during the failure period. This may not be a problem if the whole laboratory loses power. On the other hand, failure due of the computer only could result in the loss of a substantial amount of testing. Fortunately, the new microcomputers are quite reliable and have features built in to avoid complete loss of data should a power loss occur.

Some of the equipment is sensitive to dust and vibrations. The most vulnerable are the disk drives. Both dust and vibrations may affect the operation of these units and their life. We generally recommend that the computer unit be installed in an area isolated from these hazards. As an aside, micro computers are less sensitive to temperature fluctuations than earlier computers. They can now accommodate temperature ranges from 50 to 90 degrees quite easily. In general these systems are quite reliable however. Our first data acquisition system have been operating continuously for 7 years. The only failures have been with disk drives, which the users replace themselves. Some users have upgraded their computer from the initial slow XT machines.

Another disadvantage with automated data acquisition systems is the difficulty of diagnosing problems. A data acquisition system has many components, any one of which can potentially fail and disrupt the entire system. As the laboratory personnel become dependent on the system, they may not detect errors quickly. Once an error is suspected they may have difficulty pinpointing its source as a problem in the computer, the software, the sensors, the connectors, or in their misuse of the system.

CONSIDERATION IN DECIDING TO AUTOMATE

Each laboratory has its own procedure and reporting. The available data acquisition systems will usually not immediately conform to your present practice. The primary question to address in selecting a system is will it meet your primary needs. It is important to define these needs as clearly and realistically as possible before searching for a system.

A second important question deals with software. Will you purchase software or develop it in-house? For simple systems involving monitoring of one test at a time or collection of raw data only, in-house software development may be economically feasible. In-house development has the advantage that you can modify the code to best fit your needs and tailor printout and plots to your specific formats. Software to monitor several tests simultaneously, monitor different types of test, and reduce and plot data can become very involved. In-house development is difficult to economically justify. Purchased software may be considerably less expensive. A software producer usually has the collective experience of several users to check and correct deficiencies in the software. Purchased software can provide an operating system much faster than in-house development.

Costs versus expected return play an important role in selecting a system. Table 1 shows hardware and software costs for available systems. A typical lab might run 5 consolidation tests and 2 triaxial test simultaneously. They would need approximately $4,000 of instrumentation. Installation and miscellaneous items might cost an additional $1,000. A complete system costs $18,000 plus. Our studies of data times for test where data is reduced for the entire test and report quality figures and table are prepared show man time savings of 6 to 12 hours in recording, reducing, plotting, reviewing and drafting results of triaxial and consolidation test. Using an average labor cost $12 per hour gives estimated savings of $70 to $140 pertest. Thus our typical lab would have to run from 130 to 260 tests to recover the cost of the system. Maintenance costs, tax considerations, and benefits from using the equipment for other purposes will change these numbers for each lab. We recommend companies use three years as the economic life of a data acquisition system when making the decision to purchase a system. Most equipment will operate reliably for at least three ears with minimal service. Changes in technology may make the system obsolete after three years.

Maintenance and service charges should be considered as well. Typical service contracts on hardware cost from 8 to 12 percent of the purchase price per year. Some software companies offer software maintenance and support contracts as well.

Other questions to consider when choosing a system include:

- Can the hardware and software be expanded to accommodate future testing needs at a reasonable cost?
- Can the hardware be applied to other uses should the needs for data acquisition decrease?
- Can the system be modified to meet any special needs at a reasonable cost?
- Will the reduction in elapsed time for reporting test results be valuable?
- Will the data acquisition system and its products help market company services?

Finally, one should consider the accuracies required of the system. Most systems shown in Table 1 convert readings to 12 bits. This limits the maximum resolution of the system to 1 part in 4096 of full scale or approximately 0.024 % . One must consider the input levels accepted by the data acquisition system, gain provided by the system, and output levels of the sensors to determine the required resolution. Signal conditioners may be necessary to amplify the signals from sensors with low level outputs. Table 8 illustrates some examples. A pressure transducer with a maximum output of 100 mV at 100 psi and a data acquisition system with a 12 bit resolution and a programmable gain of 1 can read 2.4 m V as its smallest reading. This means that the smallest pressure difference that can be measured is 2.4 psi. this is no insufficient resolution for geotechnical laboratory. Our options would be to have a data acquisition system with a programmable gain capability, use a data acquisition with a higher resolution, use a signal conditioner, or use a sensor with sigher output level.

CONCLUSIONS

Development of the microcomputer and associated developments of related hardware has lowered the cost and improved the performance of automated data acquisition systems. Several manufacturers offer complete hardware systems suitable for automated data collection in geotechnical laboratories. At least three companies offer complete software packages to collect, reduce, print and plot results for triaxial and consolidation tests.

Principal advantages of automated data acquisition systems include reduced costs, reduced chance for human error, decreased time to produce final reports, and ability to collect and mange large amounts of data. Principal disadvantages of automated data acquisition systems include expense of sensors and software, they require higher technical skills than do manual readings, and problems may be difficult to identify.

Several factors should be considered in selecting a system. In addition to basic hardware costs, one should consider source and cost of software and service, flexibility and expandability of hardware and software, and the less tangible benefits to the company that the system may deliver.

Table 1: Typical Data Acquisition Systems

A/D Boards Only $300 - $2000
- Data Translation
- Keithley Metrabyte
- Strawberry
- Intelligent Instruments
- ConTec
- adac
- Analogic
- Advantech
- ComputerBoards, Inc.

Stand-Alone Data Loggers $1,000 - $5,000
- Campbell Scientific
- Squirrel
- Hewlett Packard

General Data Acquisition Software $200 - $3,000
- ASYST
- ASYSTANT
- EASYEST
- VIEWDAC
- LabTech Notebook

Complete Geotechnical Data Acquisition Systems $9,000 - 20,000+
- GEOCOMP Corporation
- Wykeham Farrance

Automated Geotechnical Testing Systems $15,000 - $80,000
- GEOCOMP Corporation
- Geotechnical Data Systems

GEOTECHNICAL LABORATORY TEST DATA

Project : Portsmouth Naval Base
Project No. : GTX-130
Boring No. :
Sample No. : 910448-02
Location :
Soil Description :
Remarks :

Depth :
Test Date : 8/12/91
Test Method : ASTM-422

Filename : 448-02
Elevation :
Tested by : LBH
Checked by :

FINE SIEVE SET

Sieve Mesh	Sieve Openings Inches	Millimeters	Weight Retained (gm)	Cumulative Weight Retained (gm)	Percent Finer (%)
1.5"	1.500	38.10	0.00	0.00	100
0.75"	0.748	19.00	76.00	76.00	81
0.5"	0.500	12.70	21.00	97.00	76
0.375"	0.374	9.51	18.00	115.00	71
#4	0.187	4.75	38.00	153.00	62
#10	0.079	2.00	32.00	185.00	54
#20	0.033	0.84	42.00	227.00	43
#40	0.017	0.42	54.00	281.00	30
#60	0.010	0.25	49.00	330.00	17
#100	0.006	0.15	23.00	353.00	12
#200	0.003	0.07	10.00	363.00	9
Pan			129.90	492.90	0

Total Wet Weight of Sample = -94
Total Dry Weight of Sample = 398.9
Tare Weight = 94

D85 : 22.0305 mm
D60 : 3.9782 mm
D50 : 1.4845 mm
D30 : 0.4297 mm
D15 : 0.2039 mm
D10 : 0.0978 mm

Soil Classification
ASTM Group Symbol : SP-SM
ASTM Group Name : Poorly graded sand with silt and gravel
AASHTO Group Symbol : A-1-b(0)
AASHTO Group Name : Stone Fragments, Gravel and Sand

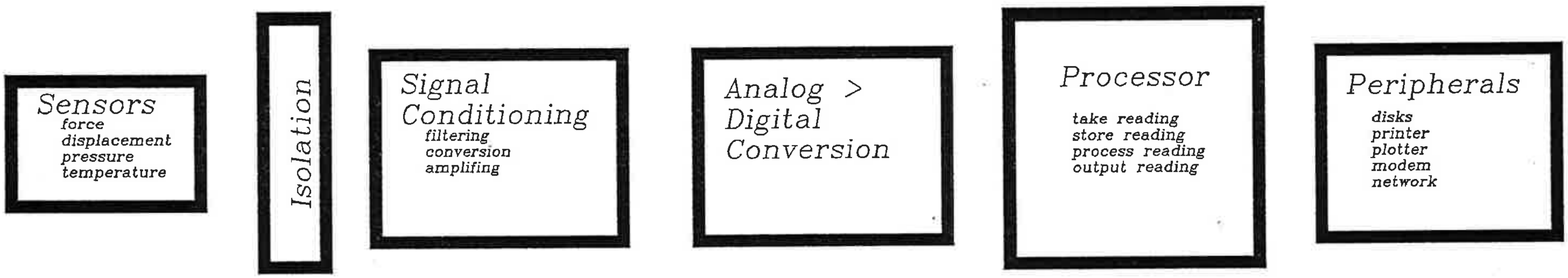
Some Benefits of Data Acquisition Systems

Less labor to run test
Less labor to report test results
See reduced test results during test
Faster completion of test because data can be obtained overnight and over weekend
Complete report of results minutes after complete test
Fewer numerical errors
Standardized test procedure and reporting
Increased amount of data allows closer study of specimen behavior
Cheap long term storage of large amounts of data
More flexibility and versatility in analyzing and reporting test results
Attract and maintain skilled labor to lab
Enhanced image for "dirt" lab

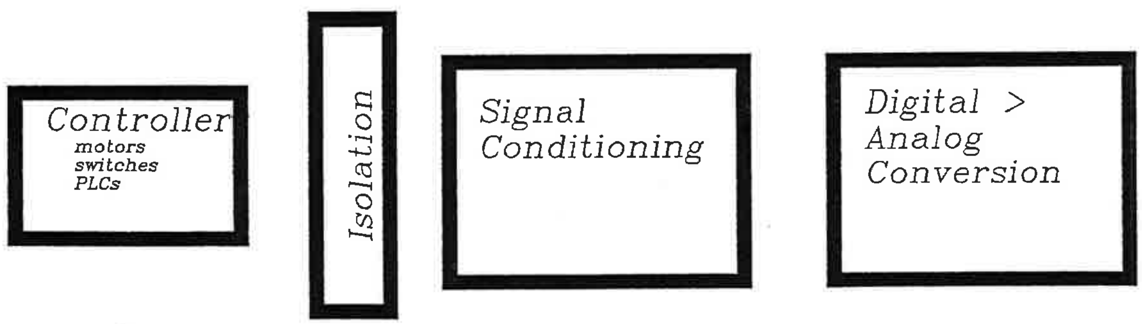
Some Drawbacks of Data Acquisition Systems

Instrumentation costs increase overall system cost
Requires more skill from technician
Difficulty diagnosing errors
- electrical noise
- sensor malfunction
- signal conditioning
- cabling
- A/D malfunction
- computer malfunction
- software problem
- test system failure

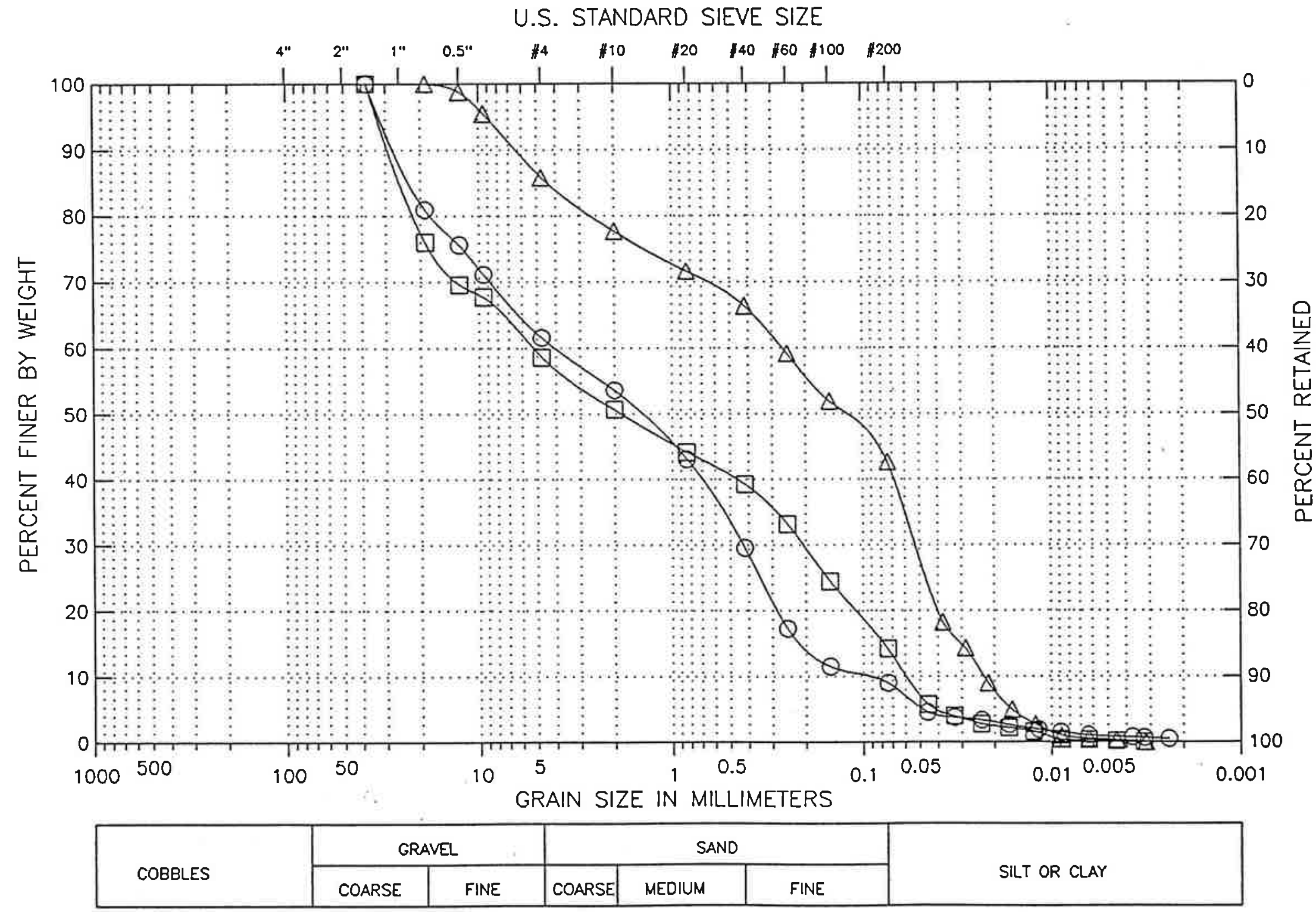
Components of Data Acquisition System



Control Function



Project : Portsmouth Naval Base
Project No.: GTX-130
Location:
Date : Sun Oct 27 1991

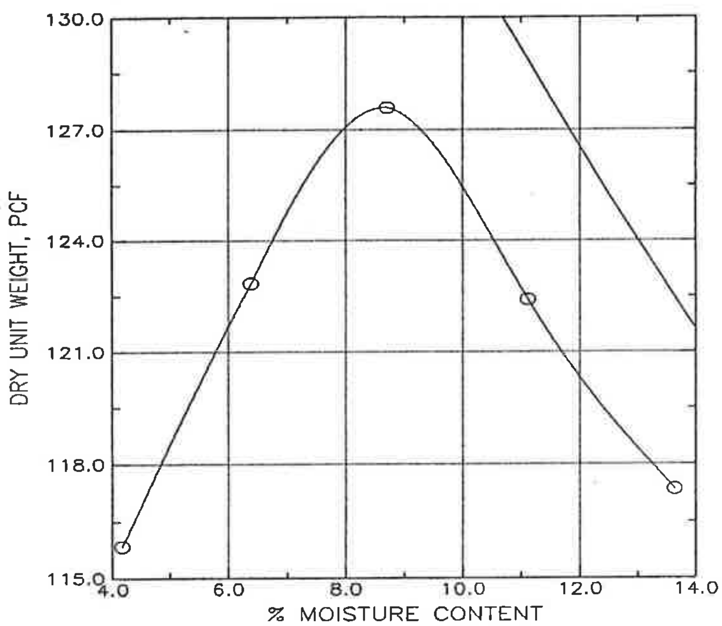


Symbol	Boring No.	Sample No.	Depth	Filename	Classification / Description
-○-		910448-02		448-02	SP-SM Poorly graded sand with silt and gravel
-△-		910395-04		395-04	Gravelly Sand
-□-		910463-12		463-12	

Figure 1

	Boring No. : B21 Sample No: SS5 Tested by : WJO Filename : TEST	Project: Harbour Graphics Project No. : 17259 Location: Port City Date : Tue Jan 08 1991

COMPACTION



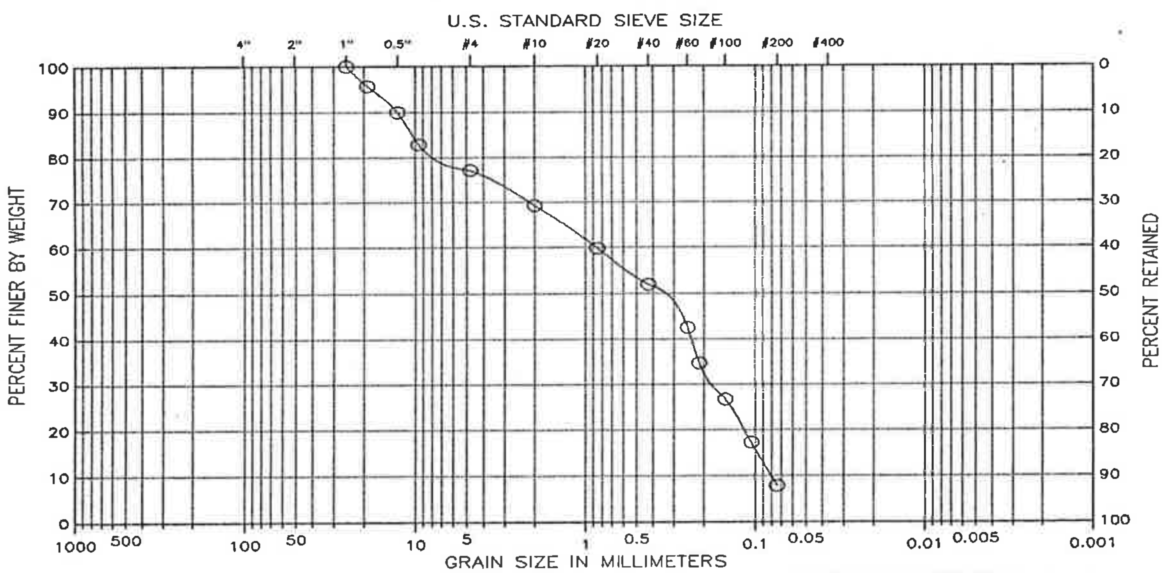
Sample Description :
Silty Sand with Gravel

Compaction Test Designation : ASTM D1557-C

Maximum Dry Density : 127.6 PCF

Optimum Moisture Content : 8.7 %

GRAIN SIZE DISTRIBUTION

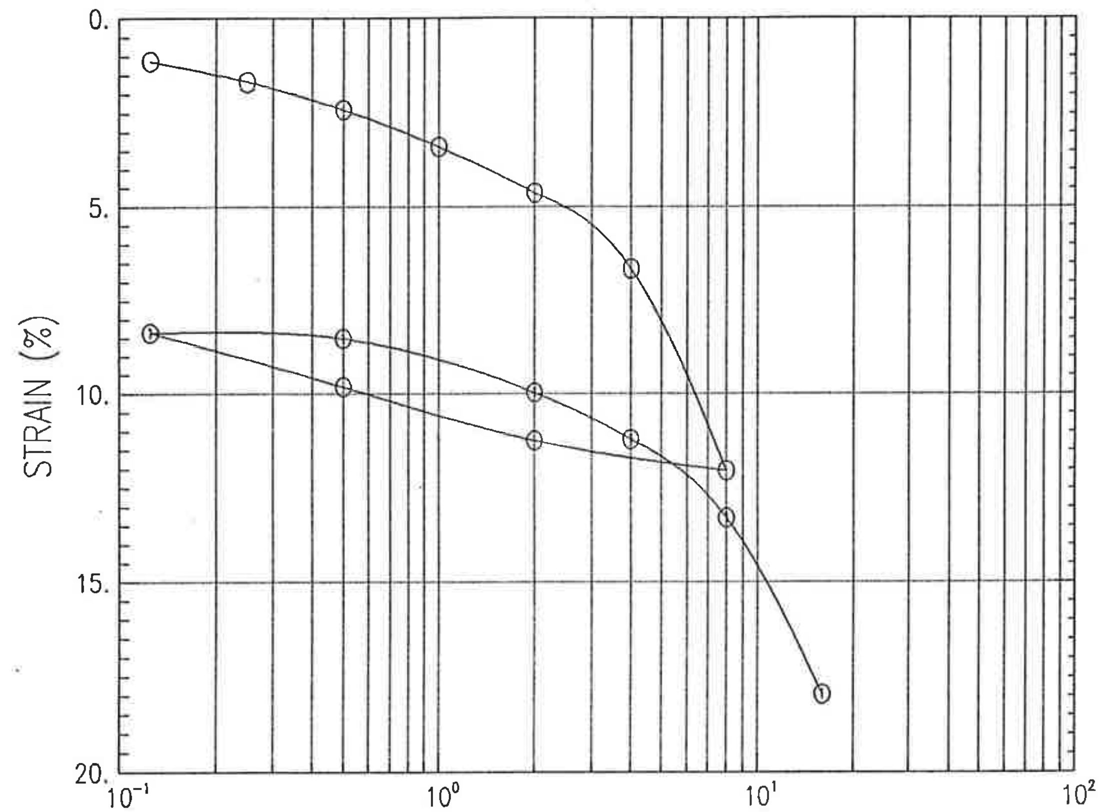


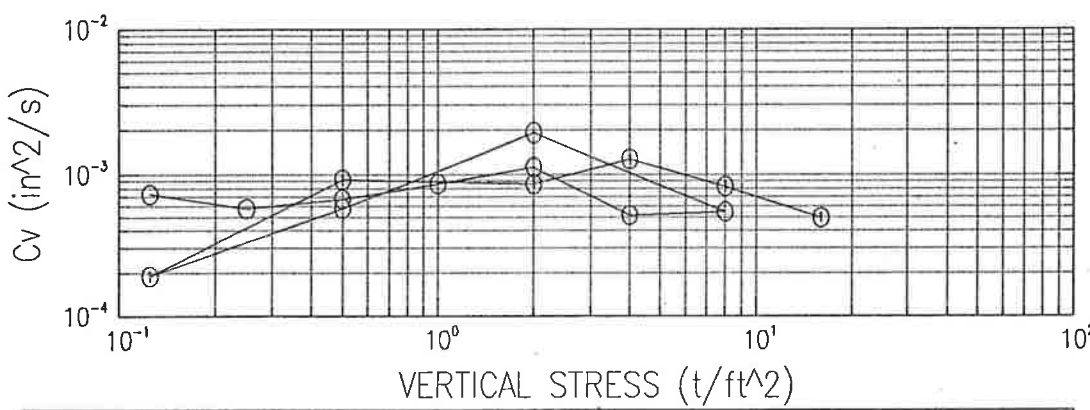
COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

UNIFIED SOIL CLASSIFICATION SYSTEM

Figure 1

CONSOLIDATION TEST
SUMMARY REPORT





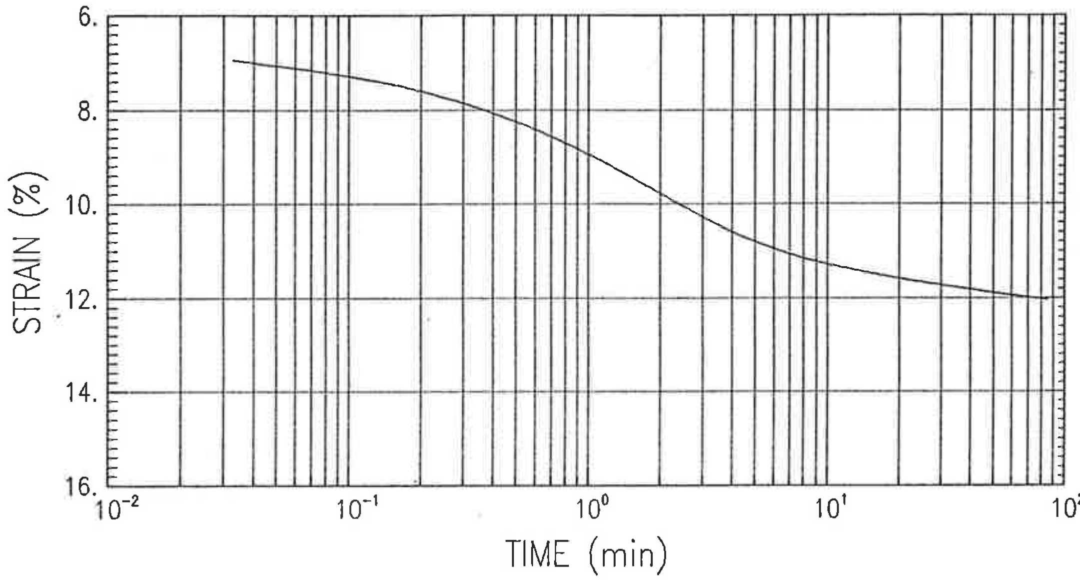
Project Name : ABC Graphics

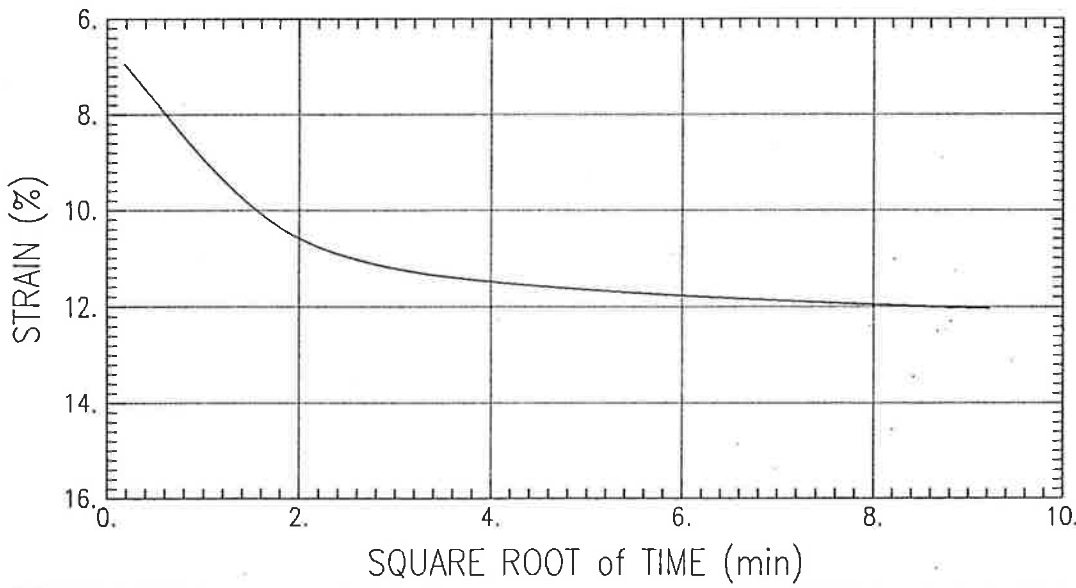
Project No : 10890 Boring No : B-13 Sample No : ST-1

Test Date : 10/29/90 Test No : 12 Depth : 12.0-13.9

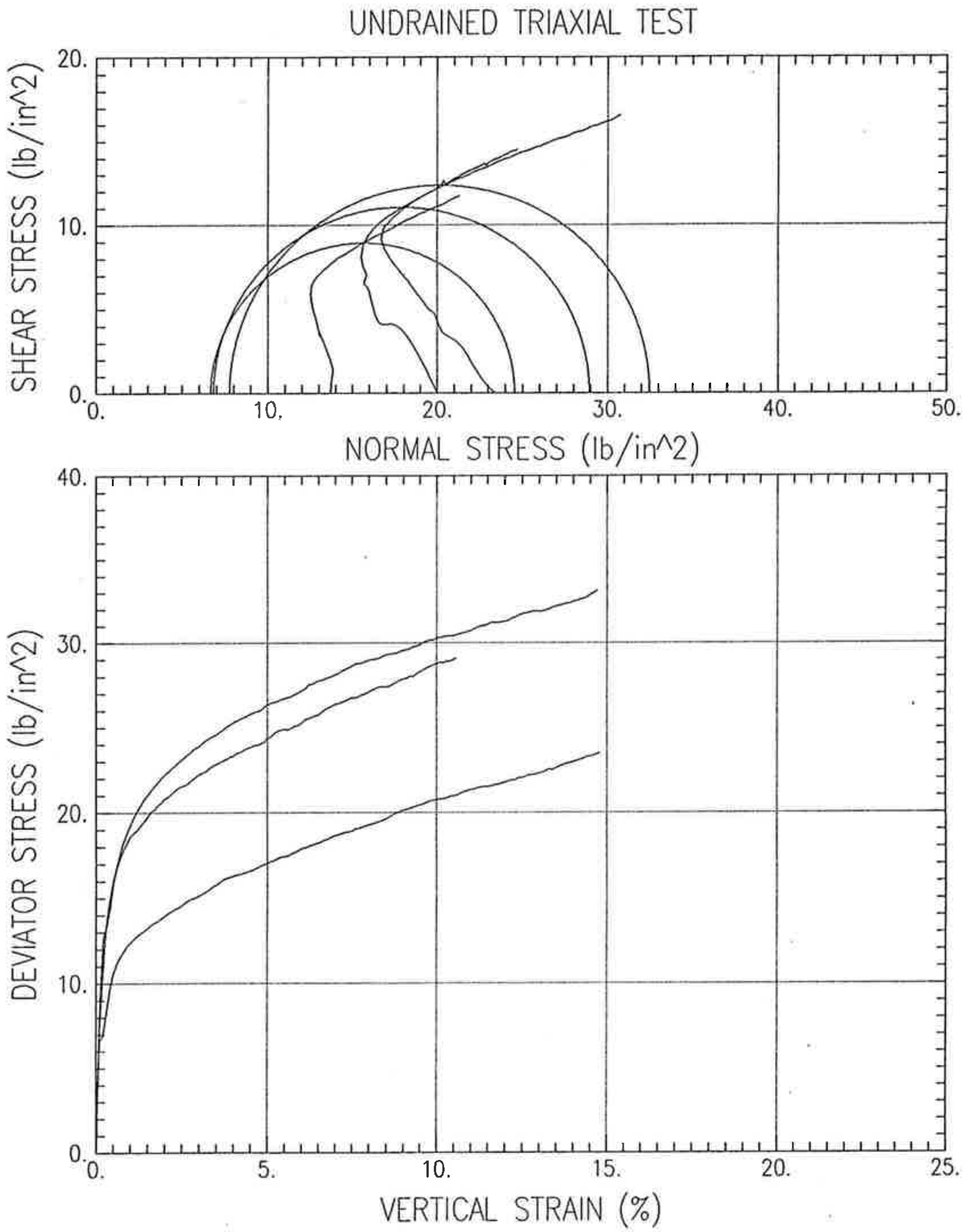
Description : Silty Clay, moderately plastic, gray green.

CONSOLIDATION TEST
TIME CURVES (STEP 7 OF 15)
STRESS : 8 (t/ft^2)



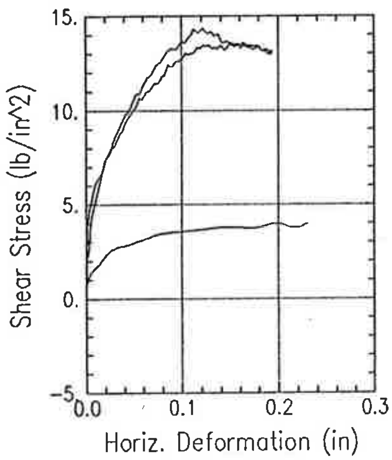


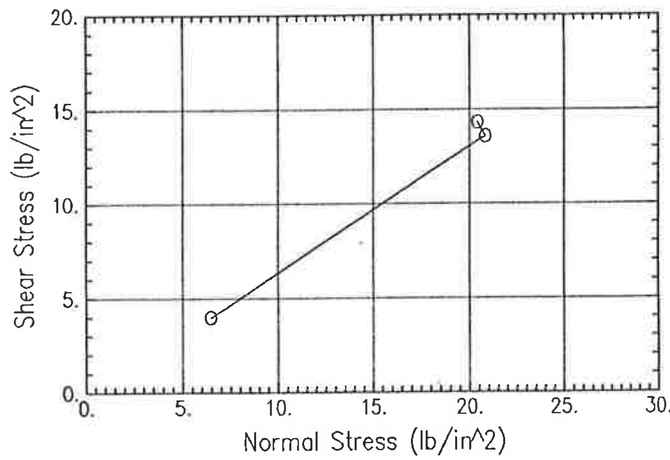
Project Name : GTX-108		
Project No :	Boring No : B-13	Sample No : ST-1
Test Date : 10/29/90	Test No :	Depth : 12.0-13.9
Description : Silty Clay, moderately plastic, gray green.		

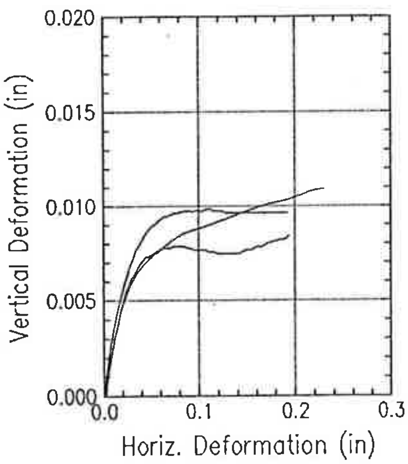


Project Name : Port Graphics

Boring No:	Sample No	Depth	Test No	Filename
B12	ST3	10−12 ft	1	a:triaxs1
B12	ST3	10−12	2	a:triaxs2
B12	ST3	10−12 ft	3	a:triaxs3







Shear Stress Parameters

Graph Symbol			O	Δ	□	
Test No.				No. 4	No. 4	
Initial	Water content (%)	w_o	0.00	0.00	0.00	
	Void ratio	e_o	0.00	0.00	0.00	
	Saturation (%)	S_o	0.00	0.00	0.00	
	Dry density (lb/ft^3)	γ_d	0.00	0.00	0.00	
Void ratio after consolidation		e_c	0.00	0.00	0.00	
Time for 50 percent consolidation		t_{50}				
Final	Water content (%)	w_f	0.00	0.00	0.00	
	Void Ratio	e_f	0.00	0.00	0.00	
	Saturation (%)	S_f	0.00	0.00	0.00	
Normal stress (lb/in^2)		σ	6.45	20.83	20.42	
Maximum shear stress (lb/in^2)		τ_{max}	3.99	13.58	14.34	
Actual time to failure (min)		t_f	40	33	22	
Rate of strain						
Ultimate shear stress (lb/in^2)		τ_{ult}	3.99	13.15	13.15	

Type of Specimen					
Classification					
LL 0.0	PL 0.0	PI 0.0		G_s 0	
Remarks	Composite Sample of Silt and Sand	Project	Gillespie & Associates		
		Area	4.91 (in^2)	Boring No.	
		Depth		Sample No.	
		Elevation		Date	06/28/91
		DIRECT SHEAR TEST REPORT			

Applications of Computers to Groundwater Seepage

prepared for:

University of Wisconsin-Madison
Extension Course on
Effective Application of Microcomputers to Geotechnical Analysis/Design

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Outline

Basics of Groundwater Flow
Methods of Solving Flow Equation
Available Computer Programs
Examples
Some Comments on Flow Analyses

Basics of Solute Transport
Dispersion and Diffusion
Example
Some Comments on Solute Transport Analysis

Concluding Remarks on Groundwater Flow Analyses

Groundwater Flow

Using Darcy's law   q = kia   and conservation of mass one can obtain

$$\frac{\delta}{\delta x}(K_{xx}\frac{\delta h}{\delta x}) + \frac{\delta}{\delta y}(K_{yy}\frac{\delta h}{\delta y}) + \frac{\delta}{\delta z}(K_{zz}\frac{\delta h}{\delta z}) + R = S_s\frac{\delta h}{\delta t}$$

where

K_{xx}, K_{yy} and K_{zz}	are permeabilities in x, y and z directions
h	hydraulic or total head
R	volumetric injection rate per unit of volume (volume flux per unit area)
S_s	specific storage (storage coefficient)

This is called the unsteady or transient, three-dimensional groundwater flow equation. It is also called the diffusion equation.

This assumes

constant density - density may vary with pressure or with solute
constant permeability - permeability may vary with pressure
constant volume of voids - soil may consolidate from seepage forces
constant degree of saturation - partially saturated soil may change
....

Solution of this equation depends on
boundary conditions - value of h or its derivative on boundary of problem
initial conditions - value of h inside the boundary at start of solution

Methods of Solving Flow Equation

Analog -

use theoretical similarities to electrical and heat flow
no longer used except look for analytical and numerical problems

Analytical closed form -

quick solution for variety of simple problems, mostly variations of flow towards a well
See accompanying table giving summary of more useful solutions.
Computer programs have been developed for some. See list

One useful set called AQTESOLV available from

Geraghty & Miller Modeling Group
1895 Preston White Drive, Suite 301
Reston, VA 22091
703-476-0335

Graphical -

hand sketching a flow net, now a lost art

Numerical -

use mathematical approximations to flow equation which result in set of simulataneous equations and solve by computer

Many computer programs have been developed to solve specific parts of the flow equation. None are outstanding and most are difficult to use.

Many are not well documented.
Few are supported
Few have been used by other than numerical specialists.
Few have been tested against real world data.
Many were developed by theoretically inclined people so that programs don't benefit from field experience in flow. Documentation and program features are dominated by bells and whistles which are numerically elegant and achievable but which confuse the practitioner.

Some Comments on Flow Analysis

Expect some flow to occur at almost every underground location.

Try to use simple but reliable approach to quantify importance of flow to your problem.

Flow may be dominated by details in stratigraphy, boundary conditions and permeabilities. Do you know these quantities with enough certainty to warrant complex flow analysis?

Beware of techniques used to simplify flow problems to 1-D or 2-D flow through a uniform soil. Oversimplification can remove the real problem.

Use simplier solutions to help define what aspects of flow are important. Work upward using increasingly sophisticated models as warranted by situation.

Many models for solute transport can be used for flow analysis. However since these models are much more complicated, it is generally better to choose a flow program if a flow analysis is all you need.

Look for programs with graphical output to allow you to examine the model more efficiently and perform parametric studies.

Flow analyses very useful to:

- identify important variables and discard the unimportant ones.
- study relative benefits and drawbacks of potential alternatives.
- identify important uncertainties and missing data that warrant more detailed study

Solute Transport

Solute transport involves movement of dissolved chemicals within the water mass.

It involves the following processes:

advection - convective transport in which solute movement is by the flowing groundwater

hydrodynamic dispersion - mixing and spreading by velocity vectors of flow

Molecular and ionic diffusion and small-scale variations in the velocity of flow through the porous media cause the paths of dissolved molecules and ions to spread from the average direction of ground-water flow

fluid sources - water of one composition is introduced into water of a different composition

reactions - some amount of a dissolved chemical is added or removed from groundwater by chemical and/or physical reactions in the water or between the water and the solid aquifer materials. This term includes precipitation, solution, co-precipitation, oxidation, reduction, adsorption, desorption, ion exchange, complexation, nuclear decay, ion filtration and gas generation

Good reference for theory

"Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water," Konikow, L.F. and J.D. Bredehoeft, Techniques of Water-Resources Investigations of the USGS, Chapter C2, Book 7, Automated Data Processing and Computations

Solute transport equation:

$$
\begin{aligned}
&\frac{\delta}{\delta x}\left(nD_{ijk}\frac{\delta C}{\delta x}\right) + \frac{\delta}{\delta y}\left(nD_{ijk}\frac{\delta C}{\delta y}\right) + \frac{\delta}{\delta z}\left(nD_{ijk}\frac{\delta C}{\delta z}\right) \\
&- \frac{\delta}{\delta x}(Cv_x) - \frac{\delta}{\delta y}(Cv_y) - \frac{\delta}{\delta z}(Cv_z) \\
&+ RC^* = \frac{\delta}{\delta t}(nC)
\end{aligned}
$$

C	material concentration M/L^3
C^*	concentration in the source term M/L^3
D_{ijk}	dispersion tensor L^2/t
n	porosity
v_i	seepage velocity in x direction L/t
R	volumetric injection rate per unit of volume $1/t$

This is known as the convective-dispersion equation.

The first line of the above equation describes change in concentration due to hydrodynamic dispersion.

The second line describes the effects of convective transport, also called advection.

The left side of the third line is the source/sink term which can be expanded to include reactions (adsorption, precipitation, oxidation, etc.)

The right side of the third line is the rate of change of concentration.

The D_{ijk} term defines the spreading and mixing caused by molecular diffusion and microscopic variation in velocities within individual pores.

While there are analytic solutions to simplier problems, most solutions to the solute transport equation are numerical and use computers for solution.

Dispersion and Diffusion

$$D = \text{Mechanical mixing} + \text{Chemical Diffusion}$$

$$D = f(v_r, \alpha_1, \alpha_2) + f(D_d)$$

v_r real velocity of fluid flow (as opposed to apparant velocity used in Darcy's law).
α_1 longitudinal dispersivity (along direction of flow) L
α_2 transverse dispersivity (perpendicular to direction of flow) L
D_d molecular diffusion coefficient for particular chemical L^2/t

At high flow velocities, mixing and dispersion are more important than diffusion.
At low flow velocities, diffusion is more important than dispersion.

Dispersion coefficients

Dispersion coefficient is larger in direction of flow α_1 than in the transverse direction α_2. These differences decrease at low flow velocities.

Typical Dispersivity
after Anderson, 1979 and Borg et al, 1976

Media	Measurement Method	Longitudinal Dispersivity, α_1 (m)	Transverse Dispersivity, α_2 (m)
alluvial sediments	single well	.03 to 7	.009 to 1
limestone	single well	12	
alluvial sediments	two wells	.01 to 15	
Dolomite	two wells	38	
limestone	two wells	15	
alluvial sediments	areal model	12 to 61	4 to 30
glacial deposits	areal model	21	4
limestone	areal model	7 to 61	1 to 20
fractured basalt	areal model	30 to 90	18 to 136

Values of dispersivity from field studies are generally several order of magnitude higher than values measured in lab.

Measuring dispersion coefficients reliably in lab or field is difficult and expensive.

Diffusion coefficient

The major ions in groundwater (Na^+, K^+, Mg^{++}, Ca^{++}, Cl^-, HCO^{3-}, SO^{4-}) have diffusion coefficients in water in range of 1×10^{-9} to 2×10^{-9} m^2/s.

In porous media the apparant diffusion coefficients are much smaller than in water (.5 to .01 times) because of the longer diffusion paths caused by the presence of soil particles and because of adsorption on the solids.

Diffusion coefficients for chemical species in clayey materials are typically 10^{-10} to 10^{-11} m^2/s.

Diffusion coefficients for chemical species in coarse-grained soils may be 10^{-10} to $< 2 * 10^{-9}$ m^2/s.

Diffusion coefficients are difficult and expensive to determine in lab or field.

Generally in granular media, the rate of diffusion is very slow compared to the rate of advection.

As a rule of thumb

in granular soils $Ki < 10^{-10}$ m/s for diffusion to be of any significance

Practically this means diffusion in granular media can be important only where no flow occurs

in clayey soils $Ki < 10^{-11}$ m/s for diffusion to be of any significance

Practically this means diffusion in clay soils can be significant only where gradient or permeability (or both) is very small.

Diffusion is primarily concern only with the bad chemicals in very low permeability materials ($<10^{-12}$ m/s) and long periods of time

- long-term storage of radioactive and highly toxic wastes

Some Comments on Solute Transport Analysis

These models can be very complicated.

Getting reliable input data for solute transport models can be expensive.

There is little reliable empirical data to work with.

For these reasons, these analyses are not done as often or as thoroughly as flow analyses.

Numerical errors can be very important. Small mesh sizes and small time steps may be required resulting in long computer times. Especially with solute transport, analyses should be made to minimize errors from grid spacing, time step size, iteration parameters and convergence tolerances.

Chemical and biological reactions may dominate field measurements and system performance.

Very difficult and expensive to establish input data for dispersion coefficients, initial conditions, boundary conditions as function of time. Many of these models exercised to get a result that agrees with historical measurements, then run the model to extrapolate into the future.

System performance may be dominated by a geologic detail that is difficult to locate and quantify.

Current regulatory stradegy of getting sites as clean as possible avoids the key question. How much solute transport is permissible? If we ever get numerical performance criteria, solute transport models are going to become much more important. Getting data to put into these models will be a major effort. The payout may be much more rational designs.

Concluding Remarks on Flow Analyses

Computers have made many flow analyses possible today that just would not be done before.

Most flow problems can be solved on today's microcomputers in a relatively short time. A few minutes for a few hundred elements in a transient flow analysis.

Availability of microcomputer has lead to more flow programs than we know how to use.

Particularily advantageous are the graphical features provided by microcomputers.

Flow analyses are helpful to:

- help identify and quantify the important physical quantities governing flow
- indicate what additional data is worth getting
- compare design alternatives - look at what ifs?
- place confidence intervals on predictions of performance
- graphically show concepts to others

Flow analyses can be misused:

- misunderstood - physics of flow are misunderstood
- overkill - modeller gets carried away with numerical elegance
- useless results - poor model, poor input, errors
- misinterpreted - results used in wrong way
- oversell - if its done by computer, it has to be believable
- lost in the fog - model so complex that can't sort out or communicate the important factors

Programs for Groundwater Flow

Program Name	Analysis Method	Description	Developer	Source	Cost
FEDAR	FEM	2-D steady state confined and unconfined flow	Taylor and Brown Univ. Calif. Berkeley		
SEEP-2D	FEM	2-D steady state confined and unconfined flow	Neuman Univ. Calif. Berkeley	U.C. Berkeley	
GEOFLOW	FEM	2-D steady state confined and unconfined flow	adapted from FEDAR	GEOCOMP Corporation	$800
FLOWNET	FEM	2-D steady state confined and unconfined flow	adapted from FEDAR by A. Urzua	Prototype Engineering	$1,100
PC-SEEP	FEM	2-D transient saturated and unsaturated flow	GEO-SLOPE International		$2,175
AQUIFEM	FEM	2-D transient confined and unconfined areal flow with wide range of boundary and initial conditions	MIT	micro-version from GEOCOMP Corporation	$1,100
AQTESOLV	analytical	various well solutions	Duffield and Rumbaugh	Geraghty & Miller Modelling Group	$500
CGAQUFEM	FEM	2-D confined and unconfined areal flow	Waterloo Center for Groundwater Research	University of Waterloo	$1,000
CROSSFLO	FEM	2-D unconfined flow in cross-section menu driven	Waterloo Center for Groundwater Research	University of Waterloo	$2,000
FLONETS	FEM	2-D flow in cross-section	Waterloo Center for Groundwater Research	University of Waterloo	$500
2D-FLOW	FDM	2-D transient flow in anisotropic, heterogeneous confined and unconfined aquifer	Trescott, Pinder and Torak (USGS)	IGWMC	$100

3D-FLOW	FDM	3-D saturated flow in anisotropic, heterogenous media	Trescott, Larson and Torak	IGWMC	$100
PLASM	FDM	2-D areal transient, confined and unconfined flow	T.A. Prickett and C.G. Lonnquist, Illinois State Water Survey	IGWMC	$100
MODFLOW	FDM	2-D areal or cross-sectional steady and transient, confined and unconfined flow	M.G. McDonald and A.W. Harbaugh USGS	IGWMC	$250
GWFLOW	analytical	collection of programs for wells with steady and transient flow	Heijde	IGWMC	$50
INFIL	semi-analytical	flow from pond into homogenous soil	Vauclin and El-Kadi	IGWMC	$50
PAT	analytical	transient flow for wells in infinite, homogenous aquifer	Kinzelback and Rausch	IGWMC	$50
PUMPTEST	analytical	analysis of well drawdown data	Beijin	IGWMC	$100
THWELLS	analytical	transient flow in isotropic homogeneous confined aquifer with wells	Heijde	IGWMC	$50
VS2D	FDM	2-D areal transient saturated and unsaturated flow	E.G. Lappala, R.W. Healy, E.P. Weeks (USGS)	IGWMC	$250
WHPA	semi-analytical	2-D steady flow for wells and streams in homogenous aquifer	T.N Blandford and P.S. Huyakorn	IGWMC	$50
RADFLOW	FDM	transient confined and unconfined radial flow to well in homogenous isotropic aquifer	K.S. Rathod, K.R. Rushton	IGWMC	$50
SOHYP	analytical	1-D unsaturated flow	van Genuchten	IGWMC	$50

AQUIX	analytical	group of programs to interpret well pumping test data	Interpex Ltd.	NWWA	$210 - $1280
GWAP	analytical	graphical well test analysis	Groundwater Graphics	NWWA	$560
PTDPS	analytical	well test analysis	Irrisco	NWWA	$445
SLUGIX	analytical	analysis of well slug test data	Interpex Ltd.	NWWA	$555
Step-Match	analytical	analysis of well slug test data	In-Situ Inc.	NWWA	$300
TYPCURV	analytical	analysis of aquifer data	In-Situ Inc.	NWWA	$300
WELLFRAC	simulation	3-D analysis of well performance analysis	Analytic & Computational Research Inc.	NWWA	$1,045
WHIP	analytical	design and interpret aquifer tests	Hydro Geo Chem Inc.	NWWA	$1,145
AQUIFER		analysis of aquifer with wells	Island Design	NWWA	$220
ARMOS/386		areal flow of water and separate phase light hydrocarbons	Environmental Systems and Technologies Inc.	NWWA	$910
FLOWPATH	FDM	flow analysis for wellhead protection	Waterloo Hydrogeologic	NWWA	$480
GLOVER	analytical	2-D analysis of homogenous, isotropic aquifer with wells	Microcode Inc.	NWWA	$345
HYDROPAL	analytical	several solutions for flow and contaminant transport	Watershed Research Inc.	NWWA	$310
INTERSTAT	FDM	interactive analysis of aquifer with pre and post processors	ESE/HydroSoft Inc.	NWWA	$800
LEAKY	analytical	analysis of aquifer with wells	Koch and Associates	NWWA	$300
MOD2DFD	FDM	enhanced version of USGS MODFLOW	Microcode Inc.	NWWA	$545
MOD3DFD	FDM	enhanced version of USGS MODFLOW3D	Microcode Inc.	NWWA	$545

Groundwater Flow

MODLMAKR		preprocessor to prepare input data for MOD3DFD and MOD2DFD	Microcode Inc.	NWWA	$345
THEIS	analytical	2 and 3-D Theis analysis with wells	Microcode Inc.	NWWA	$345
THEIS2	analytical	analysis with wells	Koch and Assoc.	NWWA	$200
UNSAT1	FEM	1-D transient flow in heterogeneous unsaturated vertical direction	van Genuchten	IGWMC	$5

Programs for Solute Transport

Program Name	Analysis Method	Description	Developer	Source	Cost
BLOB3D	analytical	3-D with uniform velocity with solute source, decay and retardation	Waterloo Center for Groundwater Research	University of Waterloo	$150
CTRAN	FEM	2-D transient, saturated and unsaturated confined and unconfined flow in hetrogeneous, anisotropic media	GEO-SLOPE International	GEO-SLOPE International	$4,170
POLLUTE	semi-analytical	1-D solution for layered and fractured media with time varying boundary conditions	R.K. Rowe and J.R. Booker	Univ. of Western Ontario	$1,100
MIGRATE	semi-analytical	2-D solution for layered systems with diffusion as significant component	R.K. Rowe and J.R. Booker	Univ. of Western Ontario	$1,600
MOC 2D	FDM	2-D nonconservative solute transport with chemical reactions	L.F. Konikow and J.D. Bredehoeft (USGS)	IGWMC	$200
MOCDENSE	FDM	2-D density dependent flow with solute transport	W.E. Sanford, L.F. Konikow (USGS)	IGWMC	$100
SUTRA	FEM	2-D saturated or unsaturated density dependent flow with adsorption and first order production	C.I. Voss, USGS	IGWMC	$120
CFEMTRAN	FEM	2-D with solute decay and retardation	Waterloo Center for Groundwater Research	Univ. of Waterloo	$1,000
CRAFLUSH	analytical	2-D transport in parallel fractures	Waterloo Center for Groundwater Research	Univ. of Waterloo	$350
FRACTRAN	FEM	2-D cross-sectional flow in fractured media with retardation and first order decay	Waterloo Center for Groundwater Research	Univ. of Waterloo	$2,000

HPATCH3D	analytical	3-D areal flow from a horizontal patch source with source, decay and retardation	Waterloo Center for Groundwater Research	Univ. of Waterloo	$150
PATCH3D	analytical	3-D with vertical patch source with source, decay and retardation	Waterloo Center for Groundwater Research	Univ. of Waterloo	$150
RCRACK	analytical	2-D radially symetric along single fracture	Waterloo Center for Groundwater Research	Univ. of Waterloo	$150
LINE2D	analytical	2-D with vertical line source with uniform velocity	Waterloo Center for Groundwater Research	Univ. of Waterloo	$150
OGATA	analytical	1-D transient solute transport	Waterloo Center for Groundwater Research	Univ. of Waterloo	$50
SUPER1D	analytical	1-D transient solute transport with time varying source	Waterloo Center for Groundwater Research	Univ. of Waterloo	$50
AGU-10	semi-analytical	collection of 1-D and 2-D solute transport solutions for homogenous, isotropic aquifer	Lawrency Berkeley Laboratory	IGWMC	$150
ASM	FDM	2-D solute transport in aquifer	Kinzelback and Rausch	IGWMC	$150
BEAVERSOFT	analytical	collection of programs for 2-D flow and solute transport	Bear and Verruijt	IGWMC	$10
EPA-VHS	analytical	predict maximum concentration from a continuous source in 1-D homogenous, isotropic aquifer	Heijde	IGWMC	$50
HST3D	FDM	3-D with flow, heat and solute transport and boundary conditions a function of time	K.L. Kippe	IGWMC	$100
PLUME	semi-analytic	concentration distribution from time varying source	Heijde	IGWMC	$50

Solute Transport

PLUME2D	semi-analytic	concentration distribution in confined aquifer with uniform flow.	Heijde	IGWMC	$35
SOLUTE	analytical	collection of solutions for nonconservative solutes in aquifer	Beijin	IGWMC	$150
TRAFRAP-WT	FEM	2-D flow in fractured or unfractured media for confined and unconfined aquifer systems	P.S. Huyakorn et al	IGWMC	$250
ONE-D	analytical	collection of programs for 1-D solute transport	Genuchten	IGWMC	$50
PESTAN		1-D dispersion of organic pollutants	Enfield (US EPA)	IGWMC	$50
HYDROPAL	analytical	collection of solutions for flow and solute transport	Watershed Research Inc.	NWWA	$310
MOFAT/386	FEM	2-D solute transport in saturated and unsaturated soil and nonaqueous phase liquid	Environmental Systems & Technologies Inc.	NWWA	$1035
PATH3D	FDM	2 and 3-D steady and transient flow comparable to MODFLOW	S.S. Papadopulos & Assoc	NWWA	$545
PC HST3D	FDM	implementation of USGS HST program	ESE/HydroSoft Inc.	NWWA	$800
PLUME		2-D steady and transient analysis of solute transport	In-Situ Inc.	NWWA	$650
PORFLOW-2D		2D steady and transient analysis of anisotropic, heterogeneous media	Analytic & Computational Research Inc.	NWWA	$545
PORFLOW-3D		3D steady and transient analysis of anisotropic, heterogeneous media	Analytic & Computational Research Inc.	NWWA	$1045
VADOSE	analytical	3D unsaturated anisotropic media	In-Situ Inc.	NWWA	$650

Solute Transport

Sources of Computer Programs for Groundwater Modelling

IGWMC
International Groundwater Modeling Center
Colorado School of Mines
Golden, CO 80401
303-273-3103

Waterloo Centre for Groundwater Research
University of Waterloo
Waterloo, Ontario
CANADA N2L 3G1
519-885-1211

Geraghty & Miller Modeling Group
1985 Preston White Drive, Suite 301
Reston, VA 22091
703-476-0335

Dr. R. Kerry Rowe
University of Western Ontario
Geotechnical Research Centre
London, Ontario
CANADA N6A 5B9
519-661-2126

Prototype Engineering, Inc.
57 Westland Avenue
Winchester, MA 01890

Solute Transport

617-729-2363

National Water Well Association
6375 Riverside Dr.
Dublin, OH 43017
614-761-1711
(recently discontinued software distribution
contact author.)

GEOCOMP Corporation
66 Commonwealth Ave
Concord, MA 01742
1-800-822-2669

GEO-SLOPE International
830 Ford Tower
633 6th Avenue SW
Calgary, Alberta
CANADA T2P 2Y5
403-269-2002

W. ALLEN MARR

President
GEOCOMP Corporation
Concord, Massachusetts

W. Allen Marr serves as Chief Executive Officer of GEOCOMP Corporation, a Massachusetts based company that provides microcomputer products and services to the engineering community. He is also director of the Engineering Services Division of GEOCOMP.

Dr. Marr has over 20 years of experience applying computers to geotechnical practice. This experience includes flow and stability assessments for over 20 dams, design and monitoring system for over 2,000 m of seepage cutoff walls in Japan, three dimensional finite element deformation analyses for excavation of Wheaton Station on the Washington D.C. metro, several computer based remote data acquisition systems for monitoring field performance, and an entire line of automated equipment for compressibility, strength and permeability testing of soils.

He is currently working on soil-structure interaction analyses for part of the new Boston Central Artery, a new stability program that includes soil reinforcement, geotechnical analyses for a Superfund site in New York, and a dewatering system to improve the earthquake resistance of a large oil refinery in Japan.

Dr. Marr received his BSCE degree form the University of California at Davis and his MS and PhD from MIT in Geotechnical Engineering. He taught at MIT for 10 years, performed research and consulted on a variety of geotechnical problems. He left MIT in 1982 to found GEOCOMP Corporation. He has published over 25 professional papers on subjects involving application of computers to geotechnical practice. In 1982, he won one of ASCE's highest awards, the Wellington prize, for his paper on criteria for settlement of tanks. He serves on the editorial board for ASTM's Geotechnical Testing Journal and is past chairman of ASTM's D18 Committee on Data Automation.

Dr. Marr is married to Victoria and has a daughter and a son. Allen and Victoria are completing renovations on a 220 year old house in historic Concord, MA. He has recently become a convert to golf.