Use of Air-Regulating Valves in Geotechnical Laboratory Testing

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Pneumatic pressure is used in many different facets of laboratory testing of soil. These uses include the application of cell pressures and back pressures in triaxial and simple shear tests and the application of shear loads in a variety of tests. Computer control of pneumatic pressure is an important element in the automation of geotechnical laboratory tests. Three-way, programmable, air-regulating valves were used in a variety of applications for automated test control, including consolidation tests, instrumented oedometer tests, and cyclic simple shear tests, and for loading systems for pavement research. The digital pressure valves have advantages over other methods of pressure control in that (a) the computer control interface is simplified, (b) open-loop control is possible for many applications, and (c) cyclic loading is easily achievable.

Automation of geotechnical laboratory tests has been an ongoing effort for the past 30 years to reduce technician time and testing costs and to increase the reliability of test data. A key element of test automation is the replacement of the manual operations required to control forces, pressures, or displacements with active computer control.

Many conventional geotechnical tests make use of air pressure to control the pore pressures and stresses applied to soil samples. In the past, manual methods of controlling air pressures have made use of suspended mercury reservoirs acting on a mercury-air interface, screw pistons, and diaphragm pressure regulators. An important element in automating many geotechnical tests is the ability to generate reproducible air pressures to control certain test parameters by using a computer-controlled air pressure-regulating system to replace these manual procedures.

Different techniques have been used to obtain air pressure under computer control. These techniques include those that use motor-controlled regulators or hydraulic actuators and those that use electropneumatic transducers. Stepper motor-controlled regulators make use of stepper motors to rotate conventional pressure regulators that would normally be rotated by hand (*1*). The stepper motors are operated by a controller mounted in an expansion slot of a personal computer or by an external controller. Motor-controlled hydraulic actuators operate in a similar fashion, in which a microprocessor-controlled motor drives a ball screw that moves a piston within a cylinder (*2,3*).

Electropneumatic transducers convert an input voltage or current into an air pressure proportional to the input electrical source (*4*). These devices usually operate in a manner in which the electrical source energizes a coil mounted on a control arm. A change in current in the coil changes the position of the control arm, which in turn changes the pressure acting on an orifice. The input voltage or current used to operate these devices may be obtained from a digital-to-analog (D/A) converter. D/A converters are readily available and are often incorporated into internally mounted data acquisition cards for use in personal computers.

These types of computer-controlled pressure devices have been used successfully in many automated geotechnical testing devices (*1,2,4,5*). However, these devices have certain drawbacks when used for some applications. First, these devices usually must be used in closed-loop control applications whereby the output pressure is continuously monitored to verify that the desired pressure is achieved and corrected if necessary. Although many algorithms can be used to optimize closed-loop control, this process takes many cycles of the controlling processor, and some time is required to achieve the desired pressure. This is normally not a problem in static geotechnical tests, but it may be undesirable for certain cyclic or dynamic tests. A second potential drawback of these devices is cost. They require either internal cards in a personal computer or external devices to provide the proper control signals and to acquire and process the data necessary for the closed-loop control. As computer hardware operates faster and becomes less expensive, these potential drawbacks are lessened, but there still is a need to investigate other commercially available devices.

The authors have investigated the use of commercially available air-regulating valves for use in the automation of geotechnical tests. Additional uses of solenoid valves for geotechnical testing are presented by other researchers (*6*). The valves used in the study described here are model PAR-15 valves manufactured by Schrader Bellows, Inc. The cost of the valve is about $650. A schematic of this device is shown in Figure 1. A 120-V alternating current (120-VAC) signal is used to operate the four solenoids. These solenoids control the division of the inlet pressure into 15 equally spaced outlet pressures. In other terms, a four-bit input signal allows 2^4 (16) different pressures to be obtained. These pressures range from a minimum value of zero to a maximum value equal to the inlet pressure. Table 1 presents an example of the design operating characteristics for an inlet pressure of 150 kPa (22 psi). The maximum inlet pressures for the valves used in the present study were 207 kPa (30 psi) and 1034 kPa (150 psi).

To provide the necessary 4-bit control signal, a digital output (DO) from a personal computer is required. DO internal cards for personal computers can be purchased and are inexpensive. However, in the present study, a relay panel was constructed so that the parallel printer port available on most personal computers could be used to drive solid-state relays. A parallel printer port provides 8 digital output channels (8-bit output) that can drive two separate air-regulating valves. The command to output a certain bit pattern from the parallel port is only one line in many

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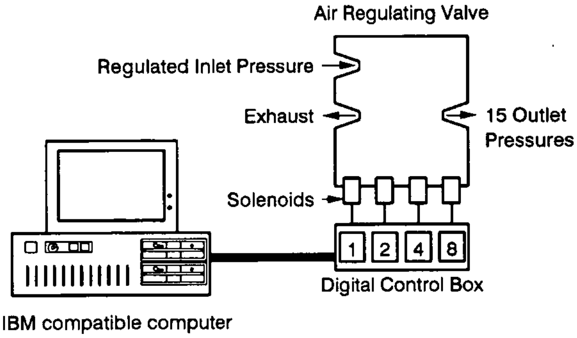

FIGURE 1 Air regulation valve system.

programming languages. For example, to send the pattern "on-on-off-on" out the first parallel printer port (LPT1), the command in BASIC is "out &H378, 13."

By incorporating two air-regulating valves connected in series, it is theoretically possible to obtain 256 different pressures. This can be done by connecting the output of the first valve to the input of the second valve.

As the first part of the research described here, the basic operation of the air-regulating valves was investigated. After the basic operation and control were understood, the valves were used for the automation of several geotechnical testing devices.

PERFORMANCE OF AIR-REGULATING VALVES

The low-pressure and high-pressure valves were tested to verify that the 15 achievable outlet pressures were evenly spaced. Shown in Figure 2 are the actual pressures achieved with the high-pressure valve with an input pressure of 552 kPa (80 psi). As can be seen, the divisions of pressure are not as linear as indicated by the manufacturer.

A series of dynamic tests was also conducted to examine the different cyclic loading patterns that could be achieved. The main loading patterns investigated were square, triangular, and sine waves. Shown in Figure 3 is a loading function in which the solenoids on the valve were switched from 15 to 2 bits at a given time interval. For this case, the output of the pressure valve was connected directly to a pressure transducer to measure the pressure.

Shown in Figure 4 is a triangular wave achieved by using the high-pressure valve. In this case, the pressure was increased by increments of 1 bit from 1 to 15 bits and then decreased back to 1 bit. The valve was connected to a pneumatic piston for this trial.

Certain factors were found to be important in the performance of the valve. Perhaps the most important factor influencing the reaction time for a desired pressure to be achieved was the volume of air that had to be pressurized. The spikes evident in Figure 3 occurred because there was a small volume of air to be pressurized for the test conditions. The pressure transducer was threaded directly into the valve, and the volume of air being pressurized was small. This caused the pressure to exceed the desired value and then to decay for a few seconds to the correct value. If the test system was changed so that a larger volume of air was pressurized, as would be the case with an air cylinder, there would be no spikes in the pressure-time relationship.

Under the test conditions in the experiment whose results are given in Figure 4, the valve was used to pressurize an air cylinder; thus, a much greater volume of air was being pressurized. In this case, no spikes were evident in the waveform. In addition, it is

TABLE 1 Theoretical Operation of Air-Regulating Valves for Inlet Pressure of 150 kPa

Solenoid Condition[a]				Output Byte	Pressure (kPa)
1	2	3	4		
off	off	off	off	0	0
off	off	off	on	1	10
off	off	on	off	2	20
off	off	on	on	3	30
off	on	off	off	4	40
off	on	off	on	5	50
off	on	on	off	6	60
off	on	on	on	7	70
on	off	off	off	8	80
on	off	off	on	9	90
on	off	on	off	10	100
on	off	on	on	11	110
on	on	off	off	12	120
on	on	off	on	13	130
on	on	on	off	14	140
on	on	on	on	15	150

[a] On indicates solenoid is energized (120 VAC applied). Off indicates that no voltage is applied to the solenoid.

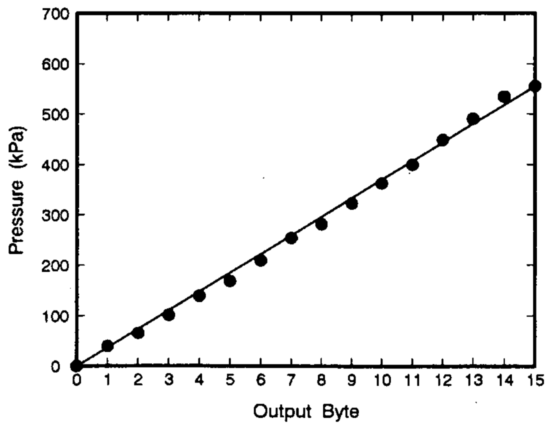

FIGURE 2 Measured pressures and ideal pressures for the high-pressure valve.

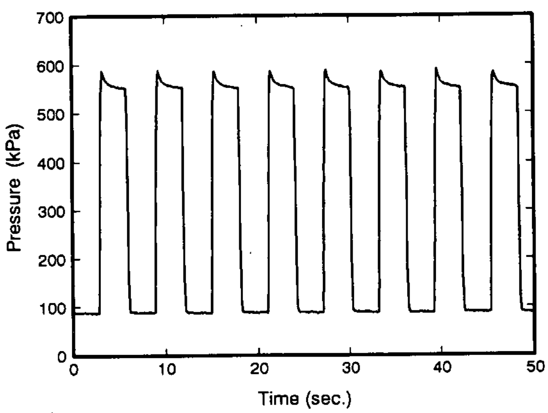

FIGURE 3 Pressure waveform achieved by switching between 15 and 2 bits.

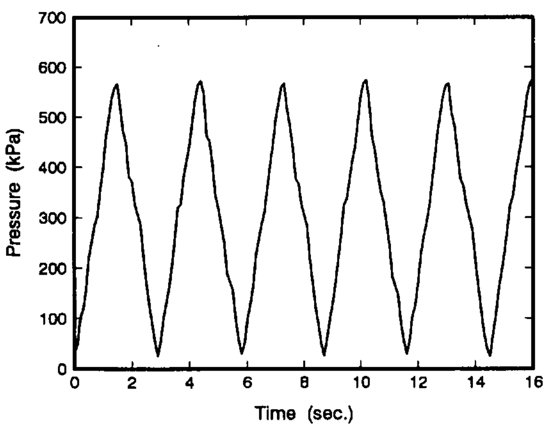

FIGURE 4 Triangular wave function achieved by increasing output to solenoids by 1 bit until 15 bits was reached and then decreasing output to solenoids by 1 bit at a constant time interval between changes.

difficult to distinguish the different pressure increments, and a relatively smooth waveform results. For the developed applications that follow, a trial-and-error procedure was used to obtain the required system performance characteristics.

APPLICATIONS OF AIR-REGULATING VALVES IN GEOTECHNICAL TESTING

The authors have used air-regulating valves in a variety of geotechnical testing applications. Usually, the valves have been combined with air pistons to apply shear or normal loads. The applications discussed in this paper are an incremental stress consolidometer, an instrumented oedometer, and a cyclic simple shear device.

Incremental Stress Consolidometer

A simple loading system was developed to conduct incremental stress consolidation tests. The basic system consisted of using two air-regulating valves to load a conventional consolidometer via a 15.24-cm-diameter air piston. Shown in Figure 5 is a schematic of the loading system. The system used a low-pressure valve with an air inlet pressure of 138 kPa (20 psi) to provide stresses of up to about 287 kPa [3 tons/ft^2 (tsf)]. The high-pressure regulator was used for stresses of greater than 287 kPa (3 tsf) to the maximum stress of about 1532 kPa (16 tsf). A linear variable differential transformer (LVDT) was used to monitor the compression of the sample. The LVDT was connected to a Metrabyte DAS-8 analog-to-digital converter in the personal computer.

During the first trials, a load cell was connected to the air piston to measure the forces applied and to ensure that the air pressures provided were repeatable. With the valve connected directly to the piston, about 5 sec was required for the desired load to be achieved. Filling of the piston with silicone oil, thus reducing the amount of air that had to be pressurized, reduced the required time to about 1 sec. A software control program was written in QUICKBASIC to operate the air-regulating valve and to acquire the data from the LVDT. On the basis of the low-pressure and high-pressure settings and on the basis of the soil specimen diameter, the 30 possible loads were calculated and tabulated. The program allows these loads to be applied to the sample in any order for compression and rebound loading patterns.

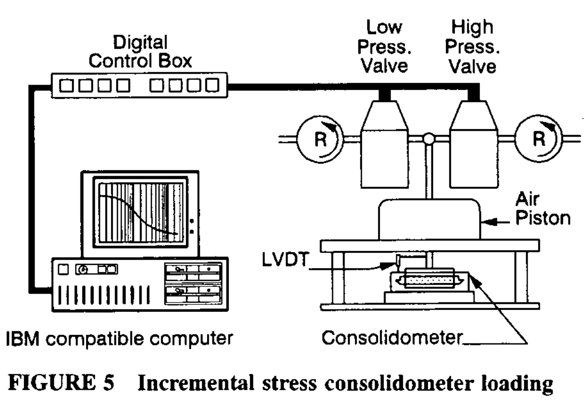

FIGURE 5 Incremental stress consolidometer loading system.

Instrumented Oedometer

A digital pressure-regulating valve with a maximum inlet pressure of 207 kPa (30 psi) was used to control the vertical pressure for an instrumented oedometer developed to investigate the effects of multiple load cycles on the value of at-rest earth pressure coefficient (K_0) (*7*). A schematic of the instrumented oedometer system is shown in Figure 6.

During a typical test, vertical stress is applied to the specimen with pressurized air that acts on a flexible membrane on top of the specimen. The pressure acting on the membrane is controlled by a program that runs on a microcomputer via a digital pressure-regulating valve. In the instrumented oedometer system, the actual pressure applied by the regulating valve is monitored by using a pressure transducer.

For each value of applied vertical stress, the horizontal stress is calculated on the basis of the outputs of the two load cells that connect the two halves of the split-ring oedometer. The horizontal stress is the sum of the load cell readings divided by the area of a vertical cross section passing through the center of the test specimen. The results of a multicycle K_0 test with the instrumented oedometer are shown in Figure 7. This test consisted of 1,000 load cycles. During each cycle, the applied vertical stress is increased to a peak value and then decreased to a minimum value by using the digital pressure-regulating valve to control the applied stress. In Figure 7, the data for only the 1st, 2nd, 10th, 100th, and 1,000th cycles are provided.

Cyclic Simple Shear Loading System

The air-regulating valves were also used for the loading system of a cyclic simple shear testing device. The simple shear apparatus was manufactured by Research Engineering, Inc. A schematic of the loading system of this device is shown in Figure 8. The shear force is applied by a double-acting piston. With the piston locked, a bias pressure is applied by a manual pressure regulator to one side of the piston. The same pressure is applied by setting the air-regulating valve to a baseline pressure somewhere in the middle of its range (i.e., 7-bit set) and adjusting the inlet port pressure until the pressures on both sides of the piston are equal. At this time, the piston can be unlocked, and the shear load applied to the specimen is zero. A cyclic shear load can then be applied by raising and lowering the control byte sent to the valve by 1 or more bits.

Shown in Figure 9 is an example of a loading waveform achieved with the cyclic simple shear apparatus. A frequency of loading of about 1 Hz was used for this test. It should be noted that the scatter in the force measurements was due to electrical noise in the data acquisition system and not to fluctuations in the pressures applied to the cylinder. The pressures in the double-acting piston observed during the test did not exhibit any noticeable scatter.

SUMMARY AND CONCLUSIONS

On the basis of the experience gained from using the air-regulating valves in the applications described here, the following conclusions can be reached.

1. The air-regulating valves provide an economical means of controlling the air pressures used for various applications in the testing of geological materials.
2. The air-regulating valves are capable of providing pressure control in an open-loop system, thus reducing the cost of the pressure control system.
3. Digital air-regulating valves can be used to provide pressure control for cyclic load tests and can produce the types of waveforms commonly used in cyclic testing of geological materials.
4. The response characteristics of the digital air-regulating valves depend on the volume of air being pressurized, and tuning

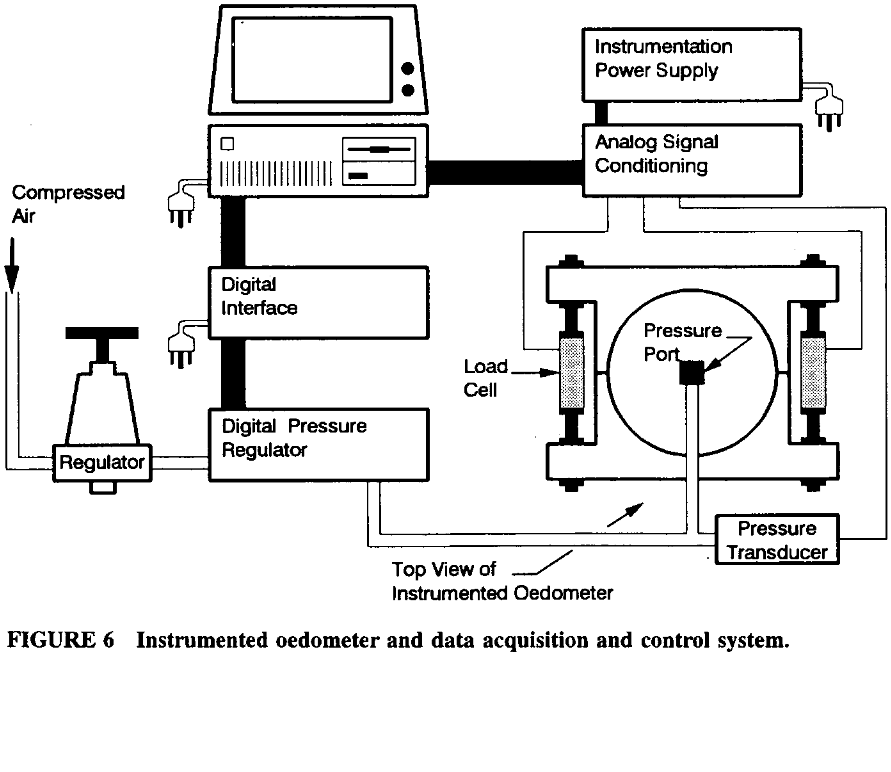

FIGURE 6 Instrumented oedometer and data acquisition and control system.

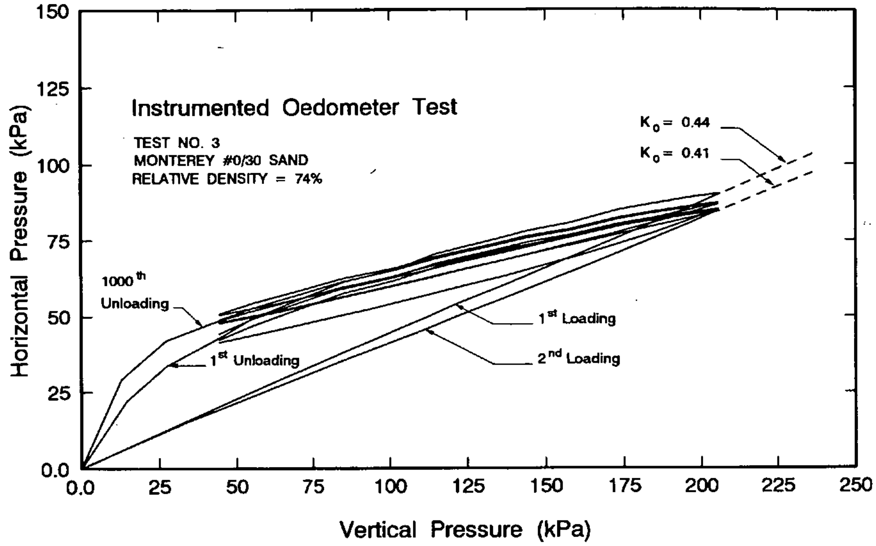

FIGURE 7 Typical test results for multicycle K_0 test on Monterey 0/30 sand using digital pressure regulator to control applied vertical stress.

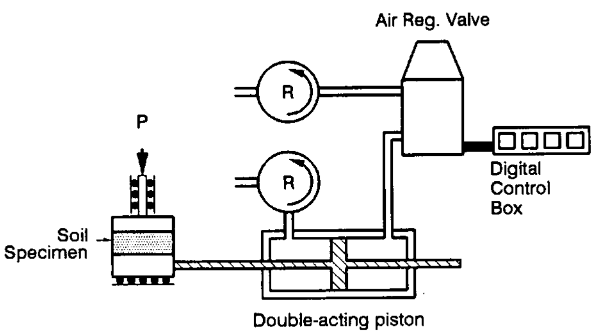

FIGURE 8 Cyclic loading system for simple shear device.

of the system may be required to achieve the required system response characteristics for a particular application.

5. The digital output of the parallel printer port available on most microcomputers can be used with a inexpensive relay board to control the digital air-regulating valve. This eliminates the more expensive interface hardware required for many of the alternative methods available for automation of pressure control for laboratory testing applications.

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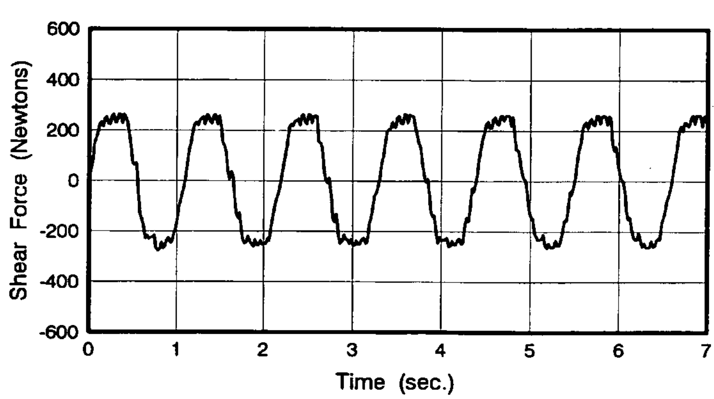

FIGURE 9 Example of loading pattern for direct simple shear apparatus.

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