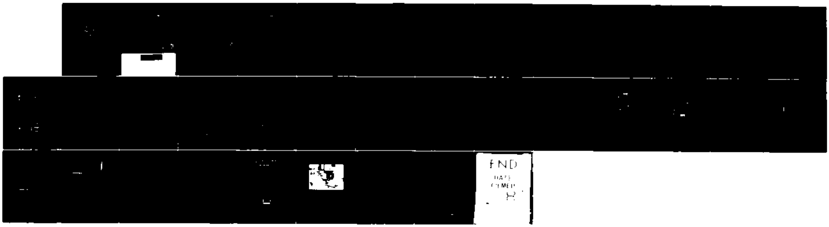
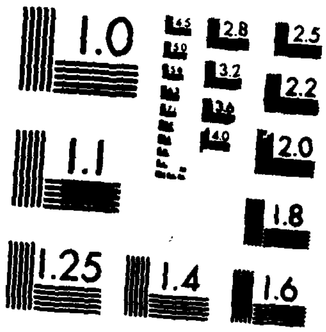
AD-A182 710 COMPUTER-BASED SYSTEM FOR TORSIONALLY AND LONGITUDINALLY CYCLING SOIL SPE..(U) TEXAS UNIV AT AUSTIN GEOTECHNICAL ENGINEERING CENTER 1/1

UNCLASSIFIED K H STOKOE ET AL. JUN 87 AFOSR-TR-87-0858 F/G 8/10 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A182 710

DTIC FILE COPY

COMPUTER-BASED SYSTEM
FOR TORSIONALLY AND LONGITUDINALLY
CYCLING SOIL SPECIMENS CONFINED
UNDER TRIAXIAL STATES OF STRESS

by

Kenneth H. Stokoe, II and Sheng-Huoo Ni

AFOSR-TR- 87-0858

COMPUTER-BASED SYSTEM FOR TORSIONALLY AND LONGITUDINALLY CYCLING SOIL SPECIMENS CONFINED UNDER TRIAXIAL STATES OF STRESS

by

Kenneth H. Stokoe, II and Sheng-Huoo Ni

a report on research
sponsored by
United States Department of Defense
United States Air Force
Office of Scientific Research
Bolling Air Force Base

June, 1987

Geotechnical Engineering Report GR87-5
Geotechnical Engineering Center
Civil Engineering Department
The University of Texas at Austin

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

ADA 182710

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for Public Release; Distribution Unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 87-0858
6a. NAME OF PERFORMING ORGANIZATION: UNIVERSITY OF TEXAS, AUSTIN; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: AFOSR/NA Bolling AFB, DC 20332
6c. ADDRESS (City, State, and ZIP Code): DEPARTMENT OF CIVIL ENGINEERING, AUSTIN, TX 78712	7b. ADDRESS (City, State, and ZIP Code): Same as 8 C
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: OFFICE OF SCIENTIFIC RESEARCH; 8b. OFFICE SYMBOL (If applicable): AFOSR/NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: AFOSR-84-0168
8c. ADDRESS (City, State, and ZIP Code): BLDG 410, BOLLING AFB, DC 20332	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2917; TASK NO. A1; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
COMPUTER-BASED SYSTEM FOR TORSIONALLY AND LONGITUDINALLY CYCLING SOIL SPECIMENS CONFINED UNDER TRIAXIAL STATES OF STRESS (UNCLASSIFIED)

12. PERSONAL AUTHOR(S)
KENNETH H. STOKOE, II AND SHENG-HUOO NI

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL TECHNICAL	FROM 7/1/84 TO 12/31/85	June 1987	33

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	SOIL SPECIMENS, TRIAXIAL STRESS STATES, RESONANT COLUMN TESTING, CYCLIC TESTING, LONGITUDINAL EXCITATION, TORSIONAL EXCITATION, MICROCOMPUTER, COMPUTER-AUTOMATED TESTING

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A microcomputer-based set of instrumentation was purchased, configured and programmed for laboratory use in resonant column and slow cyclic (RCSC) testing of soils. This system is capable of exciting cylindrical soil specimens in either torsional or longitudinal motion. Resonant testing occurs at frequencies typically above 20 Hz while slow cyclic testing occurs at frequencies of 1 Hz or less. To computerize the RCSC test, all existing manually-controlled electronic equipment had to be replaced by digital electronic equipment. This equipment had to be configured so that an HP 200 series microcomputer could control the testing and perform data acquisition automatically. To complete the automated, computer-aided, test system, a computer program named RCTEST was coded.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: DR. SPENCER T. WU	22b. TELEPHONE (Include Area Code): (202) 767-4935; 22c. OFFICE SYMBOL: AFOSR/NA

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

87 7 1 127

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the United States Department of Defense and the United States Air Force Office of Scientific Research (AFOSR), Bolling Air Force Base, Washington, D.C., for supporting this instrumentation grant under AFOSR-84-0168. Lt. Col. Dale Hokanson was the project manager. His help and encouragement are greatly appreciated. This support has significantly advanced our capabilities in laboratory testing, and the instrumentation has already played a key role in an AFOSR-funded project (83-0062), several Texas State Department of Highways and Public Transportation projects (3-8-85-437 and 3-18-87-1123), a United States Geological Survey Project (14-08-0001-22032) and a United States Bureau of Reclamation Project (6-CS-10-07860).

ABSTRACT

Sigma

A microcomputer-based set of instrumentation was purchased, configured and programmed for laboratory use in resonant column and slow cyclic (RCSC) testing of soils. This system is capable of exciting cylindrical soil specimens in either torsional or longitudinal motion. The specimens can be confined either isotropically ($\sigma_1' = \sigma_2' = \sigma_3'$), biaxially ($\sigma_1' > \sigma_2' = \sigma_3'$) or true triaxially ($\sigma_1' > \sigma_2' > \sigma_3'$). Resonant testing is performed at frequencies typically above 20 Hz while slow cyclic testing is performed at frequencies of 1 Hz or less. To computerize the RCSC test, all existing manually-controlled electronic equipment (used originally in torsional resonant testing) had to be replaced by digital electronic equipment. This equipment had to be configured so that an HP 200 series microcomputer could control the testing and perform data acquisition automatically. To complete the automated, computer-aided, test system, a computer program named RCTEST was coded (Ni and Stokoe, 1987). Besides the main program which involves test control and data acquisition, several supplementary programs were also developed to help the user in reducing test data and performing data communications with the mainframe computer at The University of Texas at Austin.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

COMPUTER-BASED SYSTEM FOR TORSIONALLY AND LONGITUDINALLY CYCLING SOIL SPECIMENS CONFINED UNDER TRIAXIAL STATES OF STRESS

1 INTRODUCTION

Dynamic and cyclic soil properties are important variables in the design of soil-structure systems to resist small-strain vibrations such as those created by vehicular traffic and vibrating machine and large-strain vibrations such as those created by earthquake shaking and blast loading. Many techniques have been used in the laboratory to investigate dynamic soil properties; for instance, the cyclic triaxial test (Silver and Seed, 1971; and Kokusho, 1980), the torsional simple shear test (Drnevich, 1972), the resonant column test (Hardin and Richart, 1963), and the cubical pulsed test (Roesler, 1979; and Knox, et al., 1982). Today, the resonant column method is still one of the best and most effective methods of evaluating the behavior of dynamic soil properties in the laboratory. This is true for several reasons. Firstly, small- to mid-amplitude strains (from about 0.0001 to 0.1 percent) can be accurately applied to a specimen and sensitively measured without difficulty. Secondly, a complex stress state can be applied to the specimen without significant modifications to the apparatus. Thirdly, it is convenient and economical to do parametric studies on the dynamic properties of soils with such equipment. This is especially true because stage testing is easily performed, and the levels at which staging begins to affect adversely the test can be accurately evaluated.

The torsional resonant column test has been developed and used to study dynamic soil properties at The University of Texas at Austin since the mid-1970's. During this period, the resonant column apparatus has been modified so that torsional shear tests could also be performed (Isenhower, 1979). Furthermore, the resonant column apparatus was modified to permit application of anisotropic loads ($\sigma_1' > \sigma_2' = \sigma_3'$) to specimens (Allen, 1982). However, all of this testing was performed manually. The purpose of the work conducted herein is to automate the resonant column/torsional shear equipment by means of a microcomputer and associated electronics. Additionally, longitudinal resonant column and axial cycling equipment are being developed. These computer-aided systems will not only simplify and standardize testing procedures but also save numerous hours of tedious and repetitious testing so that the researcher can devote more time to analysis of the test results. In addition, some possible human errors which can develop during manually-controlled testing will be eliminated.

The apparatus used in this study is termed a resonant column/slow cyclic (RCSC) device. Either torsional or longitudinal excitation is applied to the specimen. If the excitation frequency creates first-mode resonance in the soil column, the apparatus operates as a resonant column (RC), and frequencies of excitation are typically above 20 Hz. If the excitation frequency is equal to or less than 1Hz, then the apparatus operates as a slow cyclic (SC) device. Different analysis procedures are used to reduce the data depending on the mode of operation, RC or SC.

1.1 Basic Testing Configuration

The RCSC apparatus used in this study can be idealized as a fixed-free system as shown in Fig. 1. The specimen is in the shape of a right circular cylinder, either solid or hollow. The bottom of the specimen rests on a base pedestal which is rigidly fixed. The top cap and drive plate is attached to the top of the specimen. During resonant testing, the drive plate is allowed to rotate or translate freely so that torsional or longitudinal excitation can be applied at the top of the specimen. So that there is no slippage at the interfaces between the specimen and end platens, surfaces of the top cap and base pedestal are purposely roughened.

Both resonant column and slow cyclic testing can be performed with the apparatus. In the resonant column test, a constant torque amplitude with varying frequency is applied to the top of the specimen. Variation of the peak displacement with frequency of the top of the specimen is determined. From the frequency response curve, the frequency corresponding to the peak of the response is the resonant frequency. Typical resonant frequencies of soil specimens range from 6 to 120 Hz. The dynamic properties of the specimen are then determined based on the resonant frequency and either, the width of the response curve or the free-vibration-decay curve.

Instead of determining the resonant behavior of the specimen, torsional or axial cyclic tests can be performed. In these tests the load-displacement loops during low frequency excitation (typically less than 1 Hz) are measured at the top of the specimen. The cyclic properties of specimen are then calculated based on the load-displacement loops.

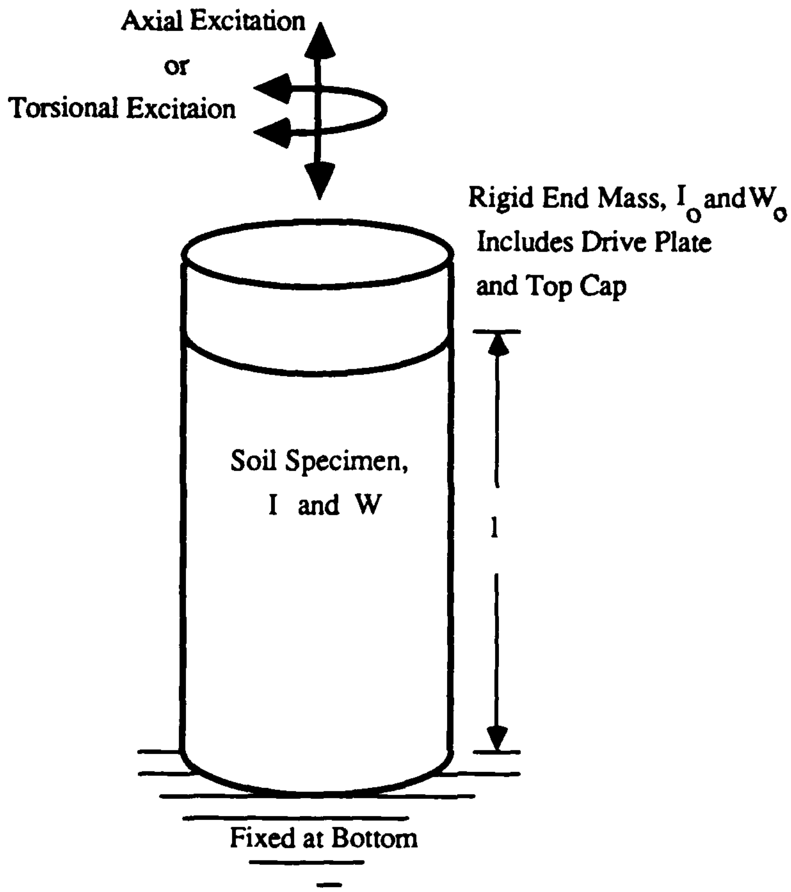
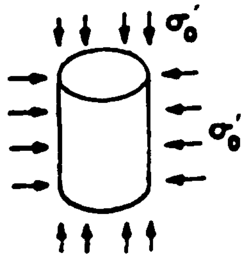
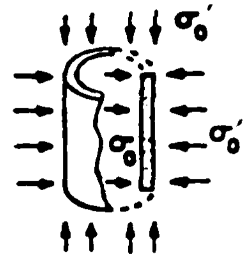
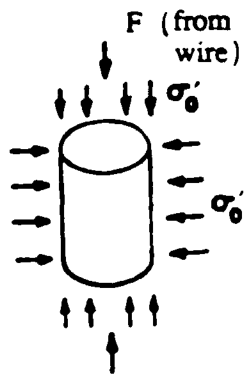
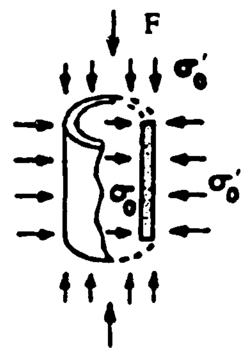
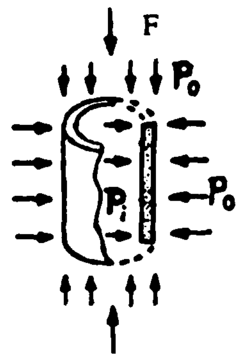


Fig. 1 - Idealization of Fixed-Free RCSC Apparatus

1.2 Definition of Initial States of Stress

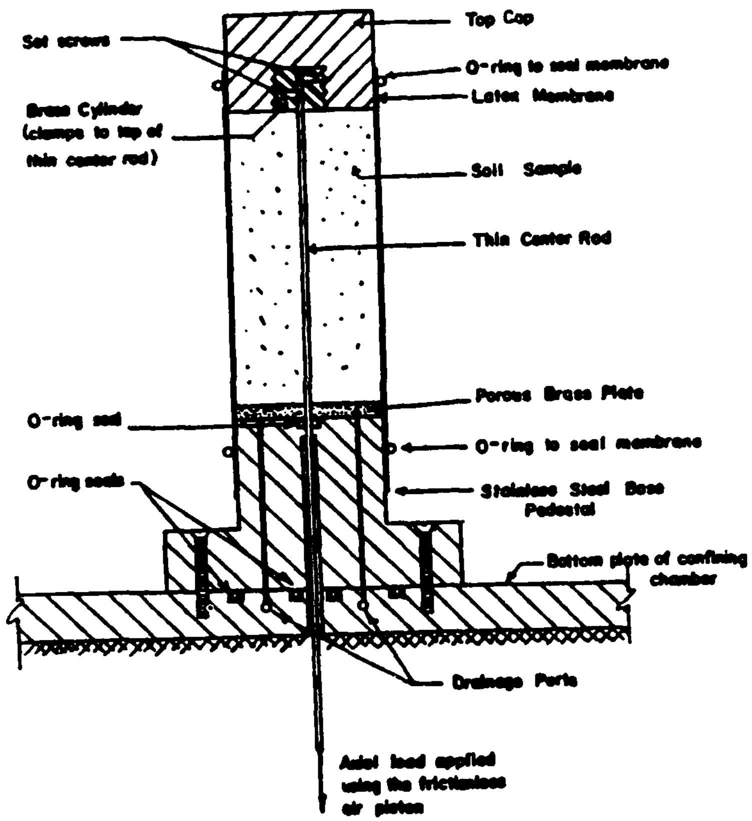
In terms of the initial confinement state before dynamic or cyclic loading, the state of stress on an element in the specimen depends on the stresses that are applied at the boundary of the specimen. The possible stress states in this study are shown in Fig. 2. When the soil column is subjected to isotropic loading, all ffective principal stresses (σ_1', σ_2', and σ_3') are equal. In this case, the mean effective principal stress, σ_o', is also equal to any one of the principal stresses.

If a vertical force is applied to the top of either a solid or hollow specimen, the state of stress in the specimen is anisotropic. In this case, σ_1' is not equal to σ_2' or σ_3'. In this work, a thin central steel wire is used to apply an increased axial load to the top cap as illustrated in Fig. 3. The vertical stress on the specimen then equals σ_1', and the cell

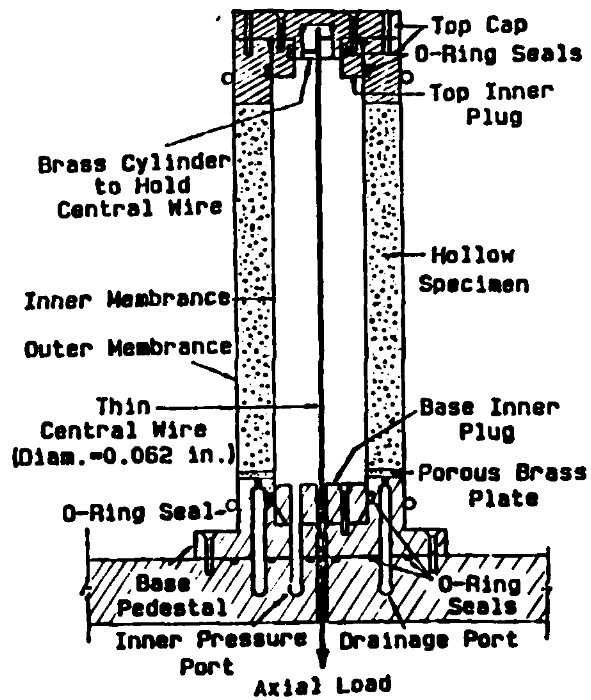
	Solid Specimen	States of Stress	Hollow Specimen
Isotropic Loading		$\sigma_a' = \sigma_1' = \sigma_0'$ $\sigma_b' = \sigma_2' = \sigma_0'$ $\sigma_c' = \sigma_3' = \sigma_0'$	
Biaxial Loading		$\sigma_a' = \sigma_1' = \sigma_0' + F/A$ $\sigma_b' = \sigma_2' = \sigma_0'$ $\sigma_c' = \sigma_3' = \sigma_0'$	
True Triaxial Loading	Not possible if σ_1 is to be oriented vertically	$\sigma_a' = F / [\pi(r_o^2 - r_i^2)] + \dfrac{(p_o r_o^2 - p_i r_i^2)}{(r_o^2 - r_i^2)}$ $\sigma_b' = \dfrac{(p_o r_o - p_i r_i)}{(r_o - r_i)}$ $\sigma_c' = \dfrac{(p_o r_o + p_i r_i)}{(r_o + r_i)}$	

* – r_i = inside radius, r_o = outside radius, p_o = outer pressure, p_i = inner pressure.

Fig. 2 - Possible States of Stress for Solid and Hollow Specimens in RCSC Apparatus



a. Solid Specimen (from Allen, 1982)



b. Hollow Specimen

Fig. 3 - Cross-Sectional View of Anisotropically Loaded Specimens in Resonant Column Apparatus

pressure equals σ_2' and σ_3'. Note that in the case of a hollow specimen, the inner cell pressure is equal to outer cell pressure. This condition is referred to as a biaxial state of stress and is written as $\sigma_1' > \sigma_2' = \sigma_3'$.

A solid specimen cannot be used for true triaxial loading. However, a hollow specimen can be loaded in a true triaxial state ($\sigma_1' > \sigma_2' > \sigma_3'$), if the outer cell pressure, p_o, is different from the inner cell pressure, p_i and an axial load is applied through the central wire.

Either the biaxial or true triaxial state of stress is referred to as an anisotropic state of stress. In other words, the specimen is subjected to anisotropic loading. During anisotropic loading, because of apparatus limitations, the major principal stress, σ_1', is always vertical.

2 SELECTION OF COMPUTER SYSTEM

Selection of a proper computer system to automate the RCSC system was not an easy task. With the rapid change that was occuring in microcomputers, it quickly became obvious that, once a computer was selected, the computer would quickly be surpassed in performance by newer models. However, if one with the appropriate characteristics was chosen, it would function well for many years.

The following points were considered in the selection process.

1. Purpose. Since not every microcomputer can be used for engineering, the purpose and application of the computer had to be clearly defined and understood.

2. Data communication. Since the computer is used for data acquisition and control, selecting a proper interface between the computer and associated test equipment is critical. Two interfaces which are currently used are the RS-232 and the IEEE-488 (or commonly called GP-IB or HP-IB). The RS-232 is a serial interface while the IEEE-488 is a parallel interface. Often, the testing characteristics determine which interface is most appropriate.

3. Testing characteristics. The testing characteristics, e.g. static testing, slow cyclic testing or dynamic testing, is also an important factor. Speed of data collection and transmission is generally the critical issue for dynamic testing such as in this work when using resonant columns of soil.

4. Availability. One must consider whether or not well-designed hardware (e.g. random access memory (RAM) and analog-to-digital converter (A/D C) interfaces) is available in the market. Consideration must also be given to the availability of software

necessary to control the hardware. Off-the-shelve software can save a lot of developmental time for the user.

5. Reliability. The reliability of the computer itself is important. A more reliable computer implies less time spent on repair. The warranty given by the manufacturer should be considered.

6. Expandability. Expandability means flexibility. Since developing software to automate the testing system is often time consuming, a more expandable computer lowers the risk of the need to buy more equipment to fit one's expanding needs and, thus, saves both time and money for the user.

7. Compatibility. The developer must consider compatibility among computers and other equipment.

8. Service. Better service saves time for the user.

9. Price. Of course, cost enters as an influential factor. One should try to purchase the best machine available, even if the purchase of other equipment has to be delayed in the short term.

Based on the criteria outlined above, an HP (Hewlett-Packard) 200 series microcomputer was selected to control the RCSC test system and to acquire data. The particular microcomputer system selected includes: HP 9836S (also called HP 236S) microcomputer, HP 9133XV (or 9133D) Winchester disc, HP 82906A graphics printer, HP 7045A six-pen plotter, and HP 98456 A/D C. The system was delivered to the University of Texas at Austin (UT) in the fall of 1984.

The HP 236S desktop computer features a 12-in. graphic CRT, two built-in 5.25-in. flexible disc drives, and memory expandable up to 2 Mbytes. It has a built-in HP-IB interface and eight built-in slots for additional memory or interface boards. The computer is enhanced by a floating-point microprocessor. The operating system of this computer is a single user HP BASIC 3.0 SYSTEM.

The HP 9133XV Winchester disc is a single volume of 14.5 Mbytes combined with a single-sided 3.25-in. microfloppy. It is used for mass storage of data, graphics and general programs. The HP 82906A graphics printer features 160 characters per second (CPS) bidirectional printing and a 9 X 11 dot matrix character cell. The HP 98640A A/D C provides seven channels of 55000 readings-per-second data acquisition (total for all seven channels).

Independent funding from the College of Engineering at UT was used to purchase the microcomputer. Funds from this project were used to purchase much of the support electronics as shown by items 1 through 8 in Table 1.

TABLE 1 -- FINAL EQUIPMENT INVENTORY OF
Grant AFOSR-84-0168
U.T. Acct. No. 26-0293-2200

Line Item	Quantity	Item Description	Cost
1	1	5-1/4" 14.4Mb Winchester Drive: S/N 2333A-26796; PO# UT-4-40418; VO# L007659; 10/10/84; mfg. Hewlett Packard; UT Tag 393451.	$ 1,735.50
2	1	ADD ON IMBYTE RAM Module, Field Installation Kit Option 010, Floating Point Math Card Series 200 Computers: PO# UT-4-40418, VO# L002787; 9/20/84; mfg. Hewlett Packard; add to UT Tag 390473.	$ 5,585.00
3	1	7 Channel Analog: PO# UT-4-40418; VO# L034335; 1/8/85; mfg. Hewlett Packard; add to UT Tag 390473.	$ 1,230.00
4	4	Micro Floppy Disk Drive: PO# UT-5-31812-CM; VO# L103705; 8/2/85; mfg. Hewlett Packard; UT Tag 404736.	$ 844.50
5	1	FORTRAN 77 and Operating System for HP9836 Computer: PO# UT-5-90110-CM; VO# L030047; 12/14/84; mfg. Empirical Research Group.	$ 1,152.50
6	1	Bit Digital I/O Module for HP3488A Switch/Control Unit: PO# UT-5-09784-CM; VO# L034336; 1/8/85; mfg. Hewlett Packard.	$ 350.00
7	1	HP-UX C-Compiler and Basic: PO# UT-6-08196-CM; VO# L027163; mfg. Hewlett Packard.	$ 345.00
8	1	Quietwriter 5201/001 with Printer Cable, Sheet Feed, and Paper Tray; PO# UT-6-00351-CM; VO# L042931; 1/22/86; mfg. IBM Corp.	$ 1,280.10
9	1	Pressure Transducers: PO# UT-5-08395; VO# L043343; 2/14/85; mfg. Validyne Eng. Sales; UT Tag 396925, 396926, 396927, 396928.	$ 1,616.24
10	2	Channel Carrier Demodulator: PO# UT-5-08395; VO# L043343, 2/14/85; mfg. Validyne Eng. Sales, UT Tag 396929, 396930.	$ 1,016.00
11	3	Transducers, Fairchild Model T-5400-115: PO# UT-5-08370-CM; VO# L110776; 8/23/85;.mfg. ITT Snyder; UT Tag 397501, 397502, 397503.	$ 1,388.40
12	3	Power Supply Lambda # LL902-OV: PO# UT-6-08409-CM; VO# L027165; 12/2/85; mfg. Lambda Electronics; UT Tag 408704, 408705, 408706.	$ 1,162.47
13	3	Demodulator: S/N 105235, 105238, 105610; PO# UT-6-08406; VO# L032327; 12/16/85; mfg. Validyne Eng. Co.; UT Tag 408695, 408696, 408697.	$ 2,378.25

TABLE 1 - FINAL EQUIPMENT INVENTORY OF
Grant AFOSR-84-0168
U.T. Acct. No. 26-0293-2200
(continued)

Line Item	Quantity	Item Description	Cost
14	6	Transducers: S/N 18224, 18225, 18226, 18227, 18228, 18229; PO# UT-6-08406; VO# L032327; mfg. Validyne Eng. Co.; UT Tag 408698, 408699, 408700, 408701, 408702, 408703.	$ 2,430.00
15	6	Proximitor 11 MM with Probe and Extension Cable: PO# UT-6-10131-CM; VO# L034444; 12/20/86; mfg. Bently Nevada Corp.	$ 3,246.00
16	2	Proximitor 7200, Probe 5MM and Extension Cable: PO# UT-6-10131-CM; VO# L034444; 12/20/86; mfg. Bently Nevada Corp.	$ 1,051.82
17	1	20811EEE Back Panel: S/N 8518223; PO# UT-36394-CM; VO# L112344; 8/31/84; mfg. Nicolet Oscilloscope Inc.; UT Tag 337671.	$ 501.79
18	1	Accelerometer Calibration system with 20 foot Cable: UT Tag 409031.	$ 855.12
19	10	Accelerometer with Cable: PO# UT-6-12551; VO# L051060; 2/14/86; mfg. PCB Piezotronics; UT Tag 409019, 409020, 409021, 409022, 409023, 409024, 409025, 409026, 409027, 409028.	$ 2,923.00
20	3	Transducers Fairchild T-5400-115 with Booster Relay and Bracket: PO# UT-6-08407; VO# L044762; 1/28/36; mfg. Esch & Associates.	$ 1,523.15
21	12	Accelerometer with Model 007B01-6 Cable: PO# UT-6-15670; VO# L059861; 3/11/86; mfg. PCB Piezotronics Inc.	$ 2,820.12
22	1	Amplifying Power Unit with 15 feet Cable: PO# UT-6-15670; VO# L059861; 3/11/86; mfg. PCB Piezotronics Inc.	$ 2,194.34
23	7	Microdot Connectors: PO# UT-5-04055; VO# L023394; 11/27/84; mfg. Malco Co.	$ 144.89
24	3	Volume Booster Relay with Mounting Brackets: PO# UT-5-08370-CM; VO# L032623, L009111; mfg. Validyne Engineering.	$ 299.08
25	5	DC-DC LVDT Transducers: PO# UT-6-08408-CM; VO# L027164; mfg. Technical Products.	$ 1,042.36
26	2	Load Cell: PO# UT-6-08408-CM; VO# L049352; mfg. Technical Products.	$ 1,045.68
27	1	Differential Pressure Transducer with Connectors: PO# UT-6-11691-CM; VO# L043823; mfg. Validyne Engineering.	$ 406.87

TABLE 1 - FINAL EQUIPMENT INVENTORY OF
Grant AFOSR-84-0168
U.T. Acct. No. 26-0293-2200
(continued)

Line Item	Quantity	Item Description	Cost
28	1	Fairchild 1634 Vacuum Regulator: PO# UT-6-12552-CM; VO# L065081; mfg. ITT Snyder.	$ 179.93
29		Various Valves and Connectors: PO# UT-6-12553-CM; VO# L036520; mfg. Arthur Valve and Fitting.	$ 251.50
30		Connectors, Microdot Plugs, Bulkhead Connectors, and Coaxial Wire: PO# UT-6-15672-CM; VO# L051643, L059023, L071499, L082219, L098271; mfg. Malco Microdot.	$ 1,001.34
31		Stainless Steel and Aluminum Plates: PO# UT-6-15113-CM; check pick up; mfg. Trident Co.	$ 790.64
32		Stainless Steel and Aluminum Plates: PO# UT-6-15761-CM; VO# L042034, L043821, L043822, L044761; mfg. Trident Co.	$ 4,948.14
33	1	Vacuum Gauge MD-CM-8.5 inch: PO# UT-6-08229; VO# L046463; 1/31/86; mfg. Dresser % SESCO.	$ 861.77
34	1	Crimping Tool and Parts: PO# UT-6-15669-CM; VO# L046826; 1/31/86; mfg. Bently Nevada.	$ 685.15
35	1	Two Channel Dynamic Signal Analyzer, HP3562A: S/N 2502A00579; PO# UT-5-31812-CM; VO# L003712; 9/25/85; mfg. Hewlett Packard; UT Tag 406321.	$23,975.00
36	1	Transit Case: PO# UT-5-31812-CM; VO# L103705; 8/2/85; mfg. Hewlett Packard; UT Tag 404737.	$ 550.00
37	1	300/1200 Baud Modem: PO# UT-5-32559-CM; VO# L096186; 7/22/85, mfg. MASSCOMP; add to UT Tag 402834.	$ 1,360.26
38	1	1 Mouse with Keyboard: PO# UT-5-32559-CM; VO# L096186; 7/22/85, mfg. MASSCOMP; add to UT Tag 386670.	$ 710.25
39	1	Version 4.2 Interactive Lab Systems for MASSCOMP: PO# UT-5-33245-CM; VO# L097812; mfg. Signal Technology Inc.	$ 4,340.78
40	1	Multi-Channel Programmable Analogue Signal Processing Filter: PO# UT-6-15682-CM; VO# L093184; (Partial payment on BAFB Grant; Acct. No. 26-0261-2480)	$ 3,555.93
41	24	Geophones: PO# UT-6-15668-CM; VO# L051062; mfg. Mark Products.	$ 1,351.95
		TOTAL	$85,130.82

3 ELECTRONIC AND OTHER SUPPORT EQUIPMENT

Before this project was funded, dynamic testing of soil specimens was performed with manually controlled electronics. In addition this testing only involved torsional excitation, not longitudinal motion. For computer controlled RCSC testing (longitudinal and torsional), most of the electronic equipment which was originally controlled manually had to be replaced by equipment with built-in HP-IB interfaces. This change-over in equipment is shown in Table 2 for comparison purposes, and the equipment inventory is given by items 9 through 27 in Table 1.

One beneficial aspect in terms of equipment is that fewer pieces of equipment are required for computer-contolled testing than manually-controlled testing. This is true because of the multitude of RCSC devices which can be controlled by one computer-based system once an HP 3488A switch/control unit is added to the computer controlled test. Computer-controlled or manually-controlled testing has no influence on the accelerometers, charger amplifiers, proximitor probes, proximitors, operational amplifier and the variable gain amplifier used, some of which were purchased for the new system.

Table 2 - Comparison of Equipment Used with the Newly Developed Computer-Aided Testing System and Original Manually Controlled Version

Method / Equipment	Computer control	Manual Control
Function Generator	HP 3314A	Wavetek M183, HP 3310B
Power Amplifier	HP 6824A	HP 6824A, HP 6825A
Frequency Counter	HP 5334A	HP 5304A
Voltmeter	HP 3456A DVM	HP 400EL AC Voltmeter
Oscilloscope	Nicolet 2090 Series or HP 98640A A/D C	Tektronix 5103N w/ 5B10N Time Base/Amplifier and 5A18N Dual Trace Amplifier
Computer	HP 9836S	None
Accelerometer	Columbia Research Lab. Model 302-6	
Charge Amplifier	Columbia Research Lab. Model 4012M	

All of the components in the RCSC testing with anisotropic loading can be monitored by either computerized or manual means. In this developmental program, however, computer-controlled testing is the focus. Accordingly, the functional components can be divided into the following seven control and monitoring systems:

1. pneumatic control system,
2. drive system,
3. motion monitoring system,
4. height-change measuring system,
5. radial-change measuring system,
6. axial load measuring system, and
7. switch and control system.

A brief discussion of each system follows.

3.1 Pneumatic Control System

Four air pressures must be controlled in the RCSC test with anisotropic loading. These pressures are: 1. the confining chamber pressure (the external pressure), 2. the inner cell pressure (for hollow specimens), 3. the piston pressure (for anisotropic loading or slow cyclic longitudinal loading), and 4. the weight compensation pressure. From a practical point of view, not all of these pressures should be controlled by the computer. For example, the weight compensation pressure is constant during longitudinal or torsional testing. In this case, use of manual control not only saves money but also preserves the simple nature of the control procedures. Since the pneumatic system is combined with computer control or manual control in this study, both control systems are discussed in next.

<u>Computer Controlled Pneumatic System</u>

To enable use of the computer to control air pressure, two kinds of transducers had to be employed. One is called a digital-to-pneumatic (D/P) pressure transducer (Fairchild model T5400), and the other is called an analog-to-pneumatic (A/P) pressure transducer (Fairchild model T5200.) Both transducers have the same output (3 to 15 psi) and input (20 ± 2 psi) pressure ranges. The D/P transducer is distinguished from the A/P transducer in that digital numbers are used to control the pneumatic pressure output . The latter, on the other hand, uses an analog input signal to drive it. Therefore, the A/P transducer maintains the feature of continuity of pressure output, but its stability depends on the stability of the input signal. The D/P transducer features a limited number of discrete pressures but incorporates the advantages of stability and the ease of control by the computer. Both transducers have the same sensitivity.

In this study, the Fairchild model T5400 D/P pressure transducer is used to control chamber air pressures. The T5400 D/P pressure transducer is an eight-bit parallel wired, input transducer. It accepts transitor-transitor logic (TTL) or 15-volt logic signals from the microprocessor and puts out a proportional 3 to 15 psig pneumatic pressure with 20 psig pneumatic input. Full-scale output (12 psi span) is divided into 255 parts based on the logic state of the eight bits. Before using the T4500 transducer, all bits are set to the reverse acting mode. In this mode, the pneumatic output is inversely proportional to the number of bits applied to the input as shown in Fig. 4.

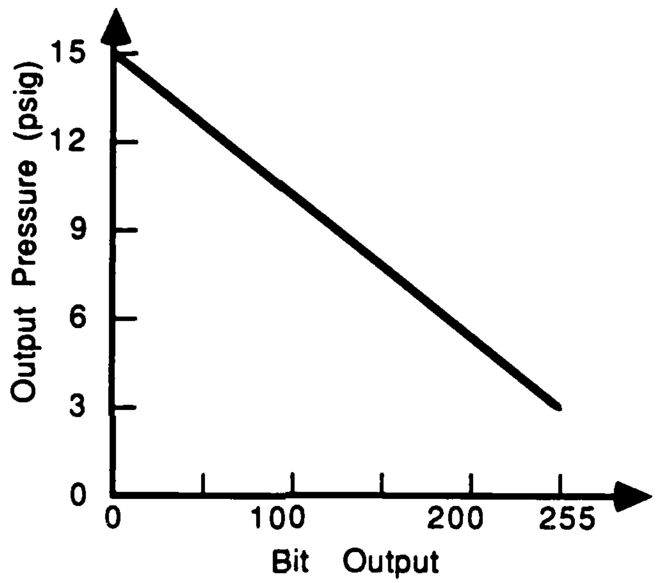


Fig. 4 - Relationship between Bit Output and Pressure Output for the Fairchild T5400 D/P Pressure Transducer

The minimum and maximum pressure output for this transducer is 3 and 15 psig, respectively. If a larger pressure output is required, a volume booster must be connected to amplify the output pressure. However, once a volume booster is used, the resolution in pressure regulation is decreased simply because of the number of discrete pressures (255) which can be selected with the D/P transducer..

In combination with the D/P transducer, a Validyne model DP15 pressure transducer is used for the pressure feedback system. When the computer commands the D/P transducer to output a particular pressure level, the Validyne pressure transducer monitors the exact pressure, and this level is fed back to the computer. The computer is then used to adjust the D/P transducer to the output closest to the pressure level required.

The configuration of the computer controlled pneumatic system for a single port is shown in Fig. 5. Of course, it can be expanded to have multiple ports with multiple D/P transducers which is necessary in this study. In this configuration, the building air supply is used to supply the required air pressure to the volume booster and D/P transducer. The volume booster is used to amplify the air output from the D/P transducer, if a larger air pressure is required. The guage in Fig. 5 is simply used to monitor visually the pressure input to the D/P transducer and final air output pressure.

When the chamber pressure in a given RCSC cell is changed during testing, the following procedure is executed by the computer.

1. Load the desired pressure level at the specified cell into the computer memory.
2. Read the current digital number from digital I/O module.
3. Read the current pressure level from pressure transducer.
4. Decide whether to increase or to decrease the cell pressure on the basis of the difference between the intended and the actual pressure level.
5. Instruct the digital I/O module to output the increasing (or decreasing) number from the current digital number to the D/P transducer for decreasing (or increasing) the cell pressure level.
6. Repeat steps 3 to 5 until the cell pressure is equal to the desired cell pressure level.

A subroutine called Pres_chg in the testing program RCTEST executes these procedures. RCTEST is discussed in Ni and Stokoe (1987) which presents the results of dynamic torsional testing of sand supported by AFOSR grant 83-0062.

Manual Pneumatic Control System

As mentioned earlier, manual pneumatic control is sometimes used, especially in those cases where the pressure level remains relatively constant throughout the test. Also, all air pressure controls are designed so that manual control can be performed if the power fails.

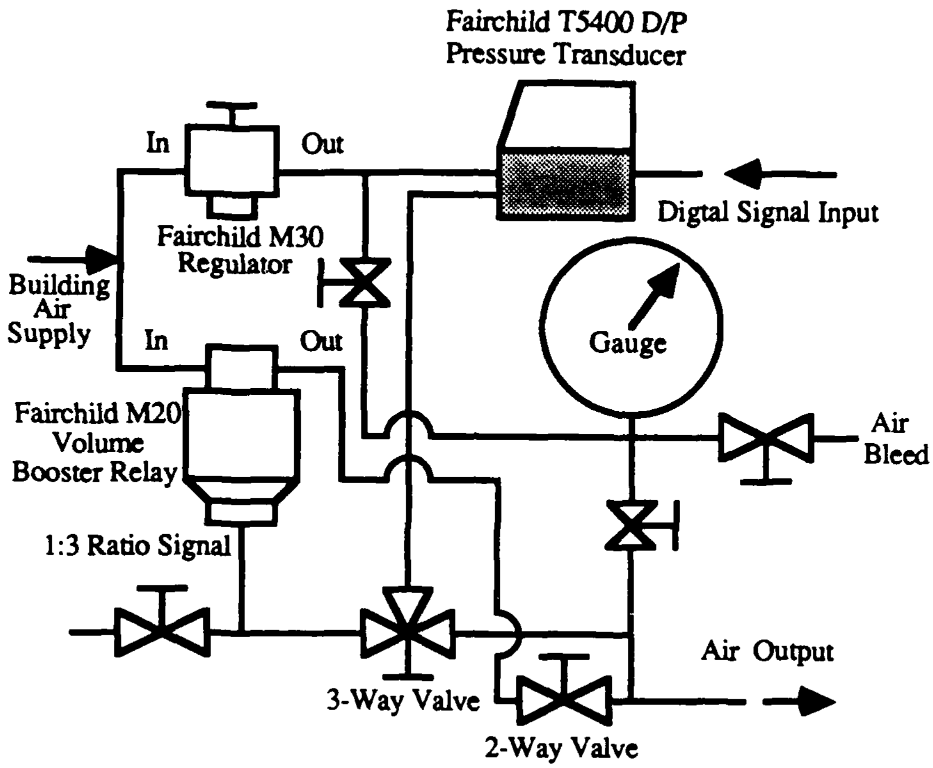


Fig. 5 - Computer-Controlled Pneumatic System

Two kinds of regulators are employed for manual control. They are the Fairchild model 30 and model 21. The model 30 regulator is a single function regulator, i.e. it can only be used to adjust the pressure level. The model 21 regulator is an infinitely adjustable differential regulator with a particular ratio of K. The output pressure of this regulator keeps the output pressure a K multiple of the input pressure. This regulator is particularly useful in controlling the inner cell pressure in testing hollow specimens.

The configuration of the manual control system is shown in Fig. 6. In this configuration, input to the adjustable ratio relay regulator is connected to the building air supply while the output is connected to the inner pressure. Whenever the outer cell pressure changes the inner cell pressure changes with ratio of K as well. Also with changing the K ratio, the internal pressure can change to any pressure level desired.

The axial load is controlled by the air piston pressure. The axial load may be constant in a torsionally excited test with anisotropic loading or it may be cyclic in slow-cyclic longitudinal test. [Note: In a slow cyclic longitudinal test, the piston air pressure is cycled using the computer controlled pneumatic system discussed in the previous section.] The model 30 regulator (marked no. 2) is used to control the air piston pressure. In this figure, the air piston pressure is also commandable by the adjustable ratio relay. The weight compensation pressure is the one pressure controlled independent of all other pressures by the model 30 regulator (marked no. 3).

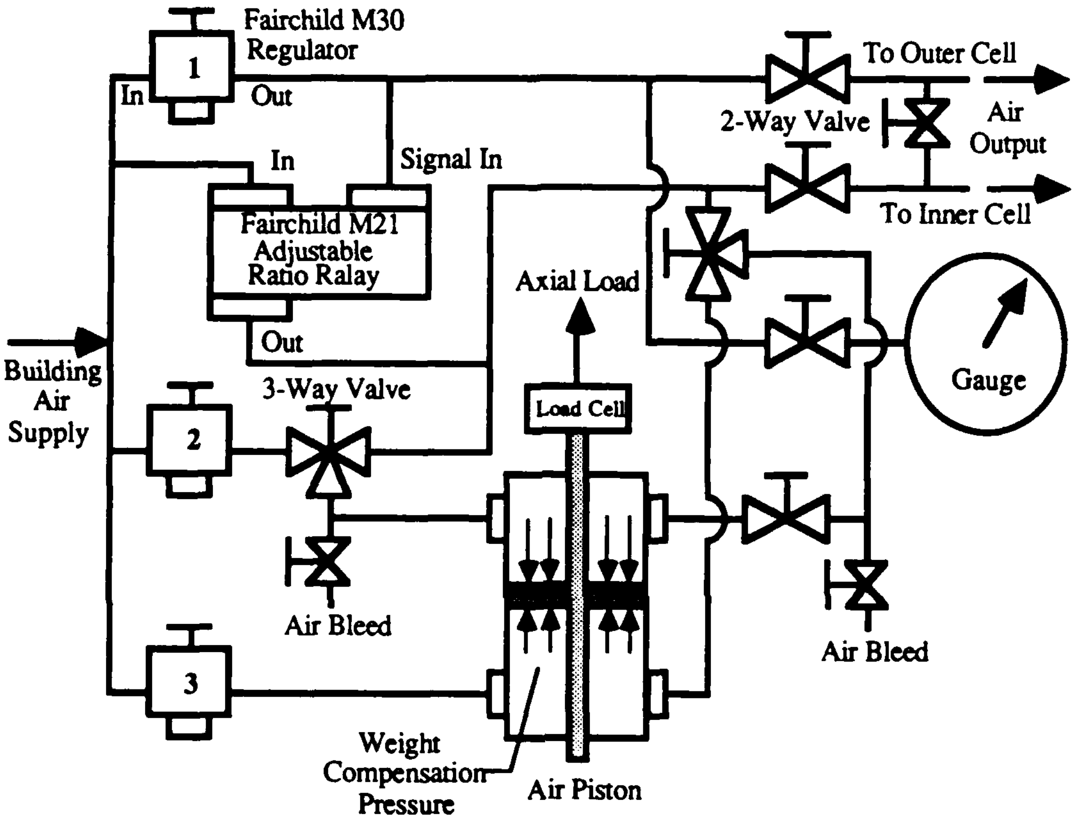


Fig. 6 - Manually Controlled Pneumatic System

The analog gauge (Heise model CM 34677) can be used to measure or monitor any of the air pressures during the testing.

3.2 Drive Systems

3.2.1 Torsional Excitation

The torsional drive system consists of the drive plate, four pairs of drive coils, and the function generator. Four holes are provided on the drive plate so that this plate can be securely attached to the top cap before testing. Four magnets are rigidly glued to the end of the four arms of the drive plate, and each magnet is suspended in a pair of drive coils.

The electronic arrangement used in the computer-aided drive system is shown in Fig. 7. The computer activates a sine wave generator (HP 3314A function generator) which inputs a sinusoidal current to the drive coils. [The frequency (f) of the sinusoid determines if slow cyclic ($f \leq 1$ Hz) or resonant testing ($f > 10$ Hz) will be performed.] The coil-magnet system translates this current into a torsional excitation of the drive plate which, in turn, excites the specimen. For high-amplitude tests (shearing strains > 0.001%), the sinusoidal input current is amplified by a variable gain amplifier (HP 6824A DC power supply amplifier) before it is input to the drive coil.

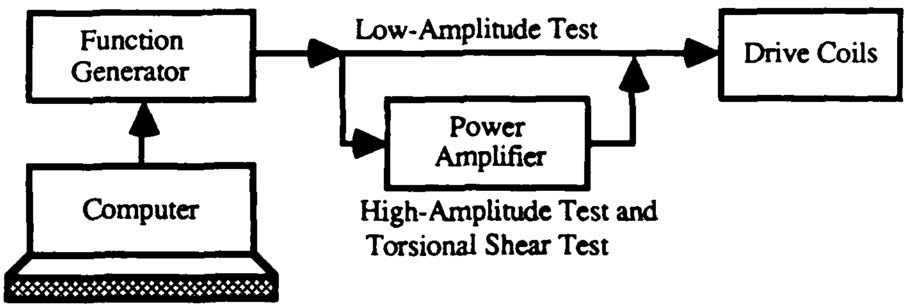


Fig. 7 - Computer-Aided Drive System

3.2.2 Longitudinal Excitation

The longitudinal drive system consists of two different drive mechanisms. Slow cyclic axial loading can be performed with the air piston and central wire arrangement illustrated in Fig. 6 or a large coil-magnet arrangement on top of the specimen. Longitudinal resonant motion is excited with the large coil-magnet arrangement.

3.3 Motion Monitoring System

Due to the different vibration frequencies applied between resonant column and slow cyclic testing, different monitoring equipment is used depending upon the frequency as discussed below.

Resonant Column Test

The electronic equipment used for monitoring longitudinal or torsional motion includes accelerometers (Columbia Research Laboratory (CRL) model 3021), charge amplifiers (CRL Model 4102M), a frequency counter (HP 5334A), a digital voltmeter (DVM) (HP 3456A), and a digital oscilloscope (Nicolet 2090 series) or an analog-to-digital Converter (HP 98640A A/D C.) The accelerometers are rigidly attached to the drive plate on top of the specimen. Horizontally mounted accelerometers are used to monitor torsional motion while vertically mounted accelerometers are used to monitor axial motion. The general arrangement of this system is shown schematically in Fig. 8.

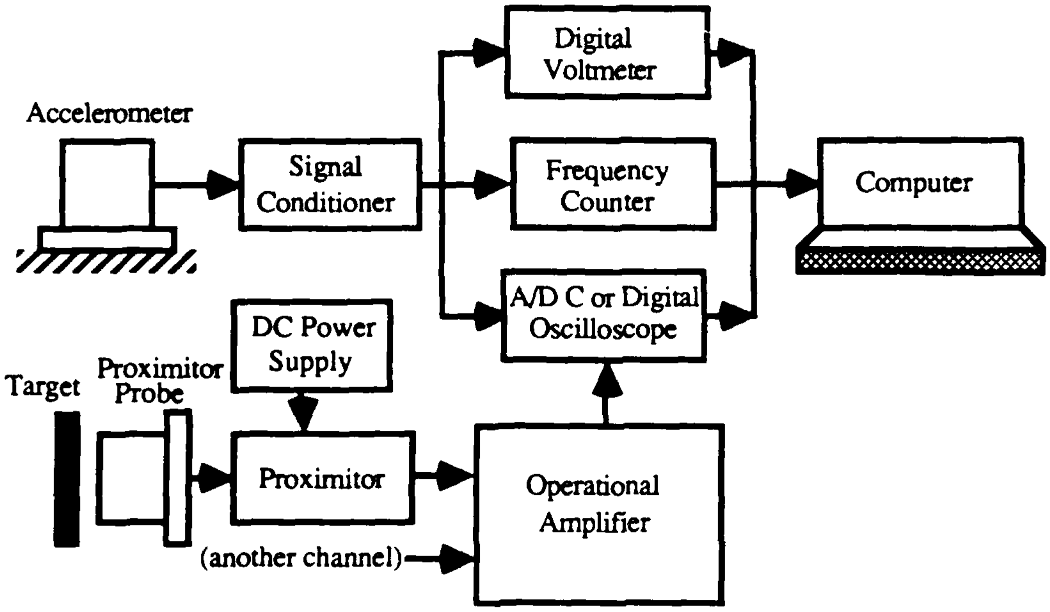


Fig. 8 - Computer-Aided Motion Monitoring System

During testing, the computer monitors torsional or longitudinal excitation of the drive plate. The computer activates the digital voltmeter (DVM) to read the true root mean square output voltage of the accelerometer and also the frequency counter to read the frequency of vibration. The amplitude (frequency) response curve is obtained by these two series of readings given the known input voltage. The digital oscilloscope or A/D C is used to obtain the free-vibration-decay curve from the accelerometer output. The output of the accelerometer is conditioned by the charge amplifier before monitoring.

Slow Cyclic Test

The electronic equipment used for monitoring the torsional or longitudinal motion during slow cyclic testing includes proximitors (Bently Nevada M3115-280-300), proximitor probes (Bently Nevada M300-00), an operational amplifier (Tektronics TM504 with AM501 plug-in), a DC power supply (Lambda M-11-902), and metal targets for the proximitor probes. The general system arrangement is shown in Fig. 8.

The proximitor is very effective tool to measure displacements at low frequencies. During measuring of torsional or longitudinal displacement, the torque or axial load is simultaneously measured. Therefore, the load-displacement loop for each type of motion can be determined from the measurment. In turn, the cyclic material properties can be determined.

3.4 Height-Change Measuring System

The equipment used for measuring changes in the height of the specimen are a linear variable differnetial transducer (LVDT) (CRL Model SH-200-53R), a function generator (HP 3314A), and a digital voltmeter (HP 3456A). The measurement system is shown in Fig. 9.

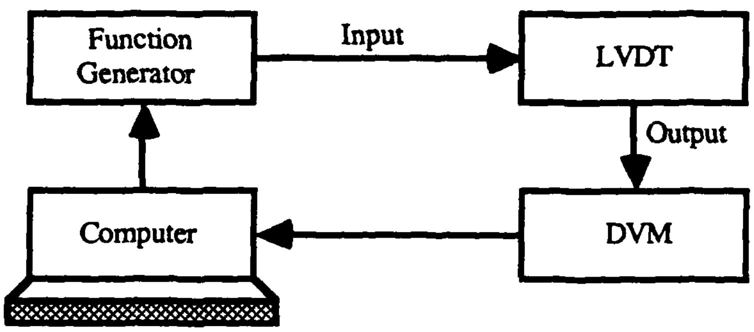


Fig. 9 - Computer-Aided Height-Change Measuring System

To measure the height change of the specimen, the computer activates the function generator to output an excitation voltage at a constant frequency of 500 Hz and a voltage level of 4.77 RMS volts to excite the LVDT. Then the DVM reads the true RMS output voltage from the LVDT. This voltage output is combined with the calibration factor of the LVDT to obtain the change of specimen height.

3.5 Radial-Change Measuring System

The equipment used to measure the change in outer diameter of the specimens are a proximitor (Bently Nevada Model 19049-03), probe (Bently Nevada Model 19048-00-10-05-02), cable (Bently Nevada Model 24710-045-000), power supply (Lambda M LL-902-OV), and DVM (HP 3456A). The arrangement of this measuring system is shown in Fig. 10.

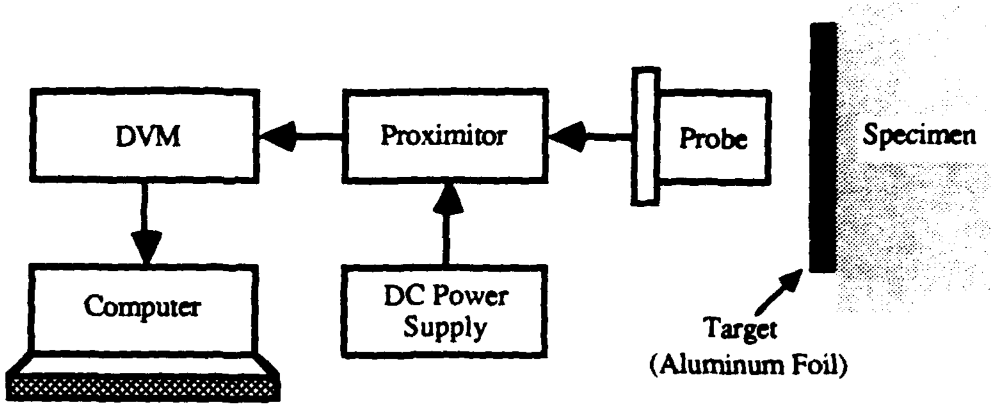


Fig. 10 - Computer-Aided Radial-Change Measuring System

As soon as the loading condition of the specimen changes, the computer scans each of the three proximitors, records their voltage, and calculates the average change of the outer diameter of the specimen. A device to measure the change of the inner diameter of hollow specimens is now being developed.

3.6 Axial-Load Measuring System

This system consists of a load cell (Lebow M 3397), power suply (Lambda M LL-902-OV), and DVM (HP 3456A). When the axial load is applied to the top of the specimen by the central wire connected to the load cell, the DVM reads the change of DC voltage from the load cell. The axial load can then be calculated knowing the calibration factor of the load cell.

3.7 Switch and Control System

As described above, many pieces of equipment are used several times for more than a particular RCSC cell during testing. To permit this function, the switch/control unit (HP3488A) is incorporated into the testing system. The switch/control unit has five slots in the rear panel, and there are many relay options that can be installed in each slot. In the present setup, the testing system can monitor up to four cells. Therefore, two dual 1 X 4 VHF switches (HP 44472A), a 10-channel multiplexer (HP 44470A), and two 16-bit digital I/O modules are installed in the switch/control unit. The relay configuration and addresses assigned to this switch/control unit are shown in Fig. 11. A three-digit number is assigned to each address. The first digit gives the location of the slot. Other digits

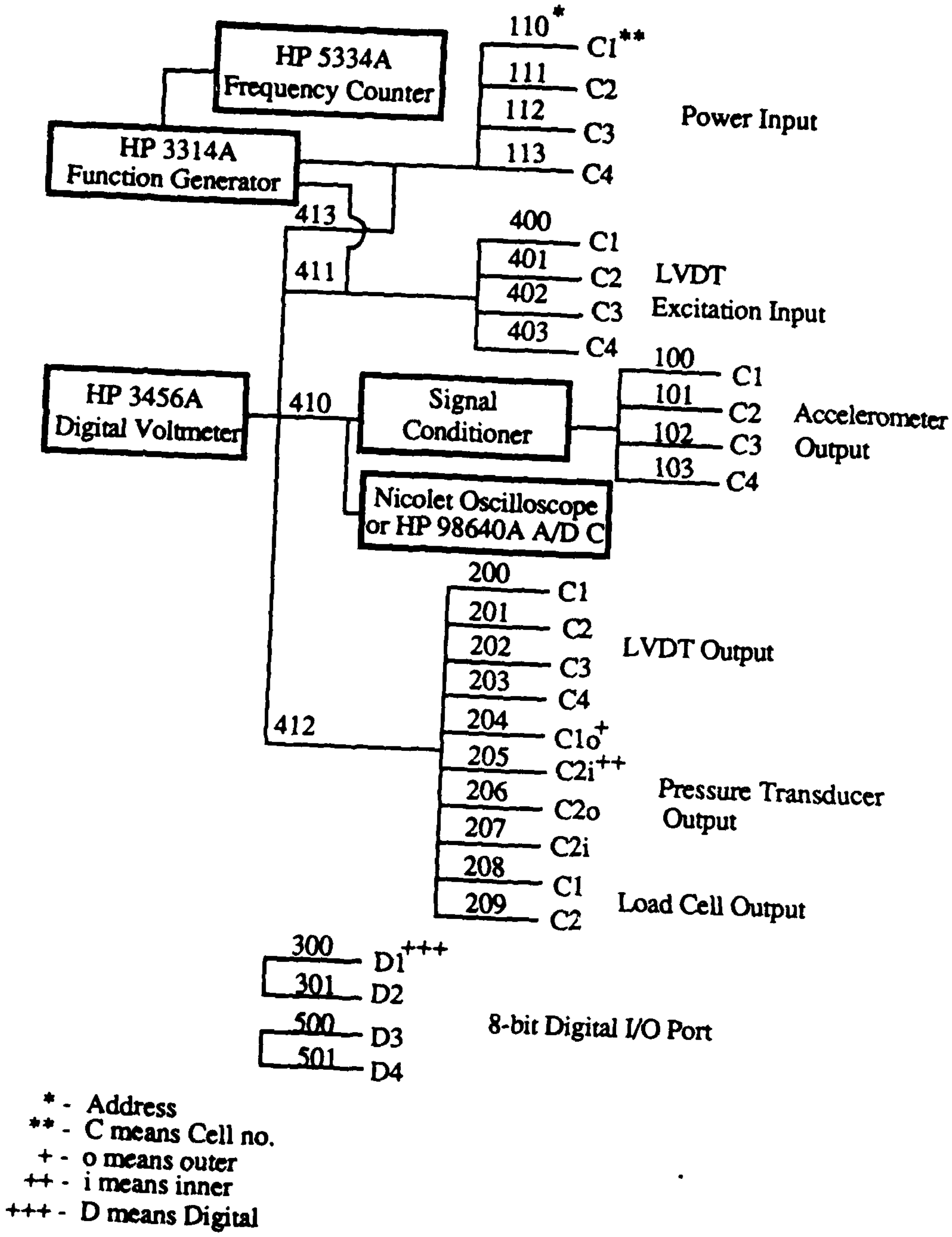


Fig. 11 - Configuration of the Switch/Control Unit and Address Assigned to the Relays

indicate the subaddress. The capital letter "C" represents the cell. "i" means inner and "o" means outer. Only cell 1 and cell 2 are equipped to run anisotropic tests in this arrangement.

During testing the computer opens or closes the relay of a particular cell so that the computer can access the appropriate measurement system and carry out the necessary measurement.

4 GENERAL CONFIGURATION OF RCSC

The configuration of the equipment for RCSC testing is shown in Fig. 12. In this configuration, the computer is the brain of the testing system. An HP interface bus (so called HP-IB, or IEEE-488, or GP-IB) is used to transmit communications between the computer and the auxillary devices. To reduce the cable capacity, coaxial-type cable is used in signal transmission between devices.

In this system configuration, the air pressure of the triaxial chamber can be controlled either manually or by the computer. The Fairchild model T5400 D/P transducer is used to control the air pressure and a Validyne DP15 pressure transducer is used to monitor the pressure level and to feedback to the computer.

An HP 3314A Function Generator is used to excite the driving mechanism through the computer. In the resonant column test, the magnitude of sample vibrations is measured using a Columbia Research Laboratory model 302-6 accelerometer. A Columbia Reasearch Laboratory model 4012M signal conditioner is used to condition and amplify the output signal from the accelerometer. The computer reads the output level and vibrational frequencies through a HP 3456A digital voltmeter and a HP 5334A frequency counter. After the response amplitude curve and free-vibration-decay curve of the sample are obtained, the resonant frequency, peak amplitude of vibration, and damping ratio can then be calculated.

In the slow cyclic test, the computer is used to activate the HP 3314A function generator to excite the specimen at very low frequencies (often less than 0.1 Hz is used). Proximitors are then used to monitor the torsional or longitudinal displacements. The load-displacement data are collected and stored in the Nicolet ocilloscope after which they are transferred to the computer. The stiffness and material damping in each mode of motion are then determined by the computer form the load-displacement loop.

The actual assembly of computer-aided testing system is shown in Fig. 13.

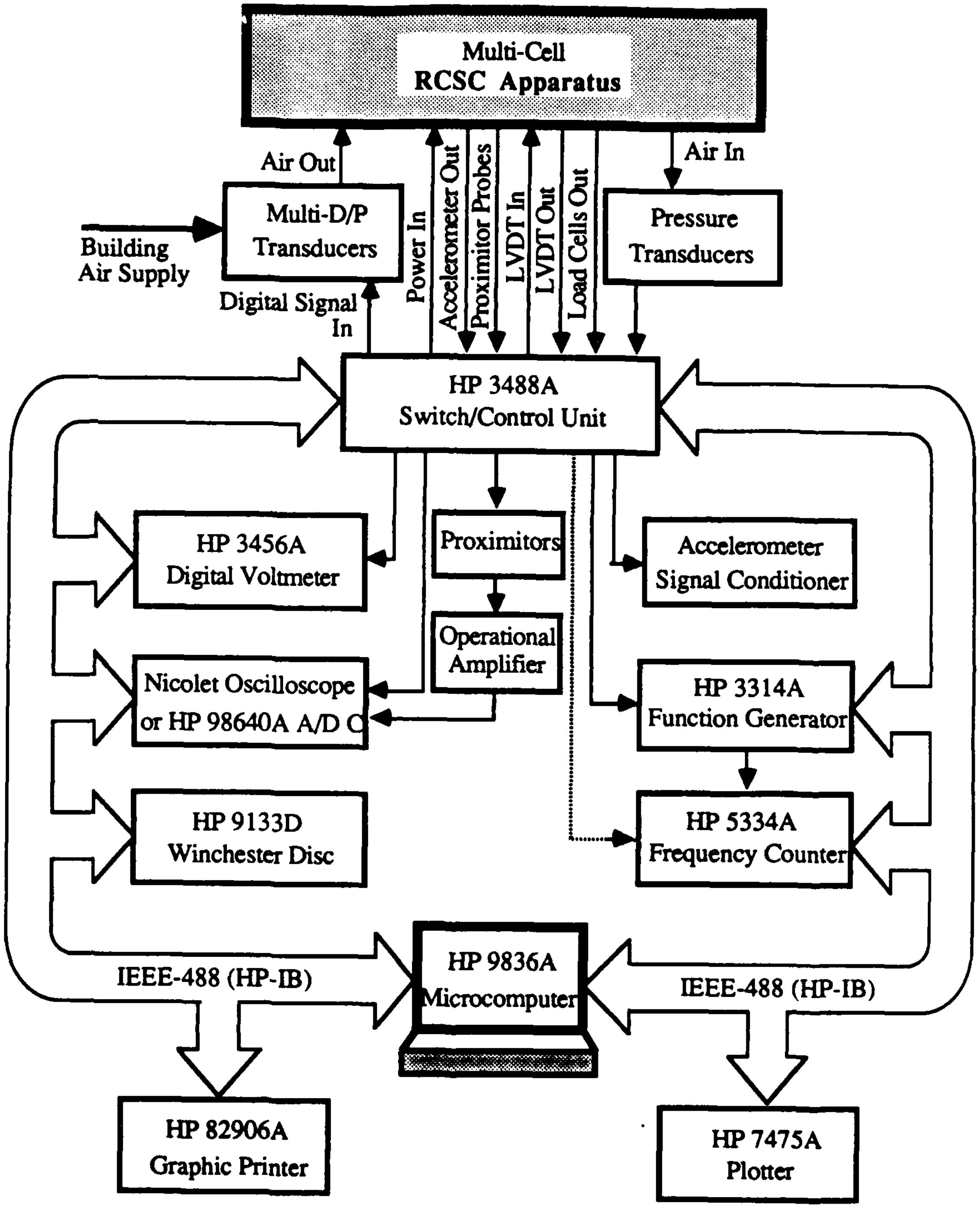


Fig. 12 - Configuration of Computerized RCSC Test Equipment

1. HP 9836S Microcomputer
2. HP 9133D Winchester Hard Disc
3. HP 3488A Switch/Control Unit
4. HP 5334A Universal Counter
5. HP 3456A Digital Voltmeter
6. Nicolet 2090 Series Digital Oscilloscope
7. CRL 4102M Charger Amplifier
8. HP 3314A Function Generator
9. HP 6824A DC Power Supply Amplifier
10. HP 82906A Graphics Printer
11. HP 7475A Plotter

Fig. 13 - Microcomputer and Associated Electronics Used to Perform Automated RCSC Testing

5 AUTOMATION OF RCSC TESTING

To automate the RCSC sytem, a program named RCTEST was developed in 1984. The latest revision of this program is May, 1986. During this period the program has been revised to provide more effective resonant column and slow cyclic testing of soil and soft rock specimens. BASIC programming language is employed to code this program. It can be used on either an HP 200 or HP 300 series microcomputer. A minimum of 640 Kb RAM memory is required. The program has the following features:

1. interactive data entry and softkey execution,
2. programmable cell pressure,
3. simultaneous testing of up to four cells (expandable),
4. ease of input data, test result, and running time for inspection or revision at any time,
5. the capability of performing tests at any prescribed time schedule or at any arbitary interval for any cell,
6. ability to add testing cells without interference with on-going testing,
7. display of informative messages or warnings on the monitor, such as the next running time and testing cell,
8. ability to utilize the computer for other computations between running times,
9. storing both high- and low-amplitude test results in different data files, and
10. the ability to assign priorities to cells having the same testing time according to their total test time at a pressurewith each test performed three minutes apart.

To fulfill these features several ideas has been applied to code this program. These ideas and the program are discussed in Ni and Stokoe (1987).

6 ADDITIONAL EQUIPMENT AND SUPPLIES PURCHASED

Other equipment and supplies were also purchased with funds from this project. Items 28 through 34 in Table 1 represent various supplies and equipment used in the construction of some components of the RCSC system. The signal analyzer and transit case (items 35 and 36 in Table 1) and the add-ons for the MASSCOMP minicomputer model 5500 (items 37 through 40 in Table 1) are used in some of the data processing of the RCSC test results in addition to being used on other studies relating stiffness and damping measured in the field to those values measured with the RCSC equipment. [The MASSCOMP minicomputer is described in Stokoe and Sheu, 1987.] The geophones (item 41 in Table 1) were initially evaluated for use as axial sources and for constrained-modulus sources but were found to be too small. They have been subsequently employed as sources in the large-scale triaxial device (AFOSR 83-0062).

7 REFERENCES

Allen, J.D. (1982), "Development of Resonant Column Apparatus with Anisotropic Loading," M.S. Report, The University of Texas, Austin, Texas, 150 p.

Hardin, B.O. and Richart, F.E., Jr., (1963), "Elastic Wave Velocities in Granular Soils," Journal of Soil Mechanics and Foundations Division, ASCE, Vol.89, No. SM1, Feb., pp. 33-65.

Hardin, B.O. and Drnevich, V.P. (1972), "Shear Modulus and Damping in Soils: Measurement and Parameter Effects," Journal of the Soil Mechanics and Foundations Division, ASCE, Vol. 98, No. SM6, June, pp. 603-624.

Hardin, B.O.and Drnevich, V.P. (1972), "Shear Modulus and Damping in Soils: Design Equations and Curves," Journal of the Soil Mechanics and Foundation Division, ASCE, Vol. 98, No. SM7, July, pp. 667-692.

Isenhower, W.M. (1979), "Torsional Simple Shear/Resonant Column Properties of San Francisco Bay Mud," Geotechnical Engineering Thesis GT80-1, Civil Engineering Department, University of Texas at Austin, Austin, TX, Dec., 307 p.

Knox, D.P., Stokoe, K.H., II and Kopperman, S.E. (1982), "Effect of State of Stress on Velocity of Low-Amplitude Shear Wave Propagating along Principal Stress Directions in Dry Sand," Geotechnical Engineering Report GR 82-23, University of Texas at Austin.

Kokusho, T. (1980), "Cyclic Triaxial Test of Dynamic Soil Properties for Wide Strain Range," Soils and Foundations, JSSMFE, Vol. 20, June, pp. 45-60.

Ni, Sheng-Huoo and K.H. Stokoe, II, "Dynamic Properties of Sand Under True Triaxial Stress States from Resonant Column/Torsional Shear Tests," Geotechnical Engineering Report GR87-6, August, 1987 (in press).

Roesler, S.K. (1979), "Anisotropic Shear Modulus Due to Stress Anisotropy," Journal of the Geotechnical Engineering Division, ASCE, Vol. 105, No. GT7, July, pp. 871-880.

Sheu, Jiun-Chyuan and K.H. Stokoe, II, "Instrumentation for the Study of Transient Seismic Waves in Soil, Rock and Pavement," Geotechnical Engineering Report GR87-4, June, 1987 (20 pp).

Silver, M.L. and Seed, H.B. (1971), "Deformation Characteristics of Sands under Cyclic Loading," Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol. 97, No. SM8, pp. 1081-1098.

DATE
ILMED
-8