AUTOMATION OF OYO'S 4 CELLS TRIAXIAL APPARATUS

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Abstract

With the popularization of triaxial compression testing based on the concept of effective stress, we at OYO Corporation have striven to increase the processing ability, efficiency and data capacity by triaxial testing equipment. Accordingly, we have perfected a test equipment bank of 4 triaxial cells, capable of storing and automatically processing data.

This apparatus is made up of sets of 4 testers. In order to be able to carry out triaxial compression testing and creep testing over long periods of time, each triaxial chamber was provided with its own consolidation density and compression apparatus. Axial pressure can be controlled by a bellowframe cylinder. On the basis of our experience with a 10-bank testing system, with data recorded by an HP 1000 on-line system computer with a real time programming function, we developed a greatly flexible off-line system that uses a microcomputer to control an 8 bank testing system.

This paper is mainly concerned with a description of the triaxial compression testing apparatus, the advanced automation and characteristics of the system.

1 INTRODUCTION

The amazing strides that have been recently taken in the field of electronic engineering notwithstanding, automation in the area of soil testing has been remarkably delayed. Now this area can at last be said to have begun the process of modernization.

OYO Corporation's first efforts at automation of soil testing began in 1966 with its unconfined compression apparatus. This involved the use of a synchronous motor to establish a fixed speed of compression, a differential transducer to detect amount of compression of the specimen as well as amount of deformation of the proving ring and the installation of an X-Y recorder for automatic recording. This can be said to have been no more than an elementary approach to automation. Special graphic paper was prepared for correction of a variable cross-sectional area of the specimen during testing. Next, by using the self-recording unconfined compression apparatus, a self-recording apparatus was perfected for triaxial apparatus in 1970.

The latter equipment is both more accurate and more convenient to use than the unconfined compression apparatus. Furthermore, with the triaxial apparatus, initial height and cross-sectional area to an accuracy of 0.10 mm and 0.01 cm^2, respectively, can be set by a vernier scale, an analog computer may be used for cross-sectional area correction during testing, and also, by using a pressure transducer, pore water pressure may be automatically recorded. A 2 channels X-Y recorder designed to automatically record stress-strain and pore water pressure-strain curves was used.

In the field of soil testing, consolidation test requires the most time and effort. Originally, in the early stages of this test, a large number of persons are required, even though only for a short time. In addition, a large volume of data is produced, requiring a large number of persons to process this data. Thus, with the objective of reducing the number of persons required, increasing data processing efficiency and eliminating readout errors, in 1973 a bank of 70 automated consolidation apparatus was built. As a result of one year of comparative testing with the old type of consolidation apparatus, it was found that the above mentioned objectives were met satisfactorily. Since 1975, this automatic testing facility has been practically in use.

Thus, by 1973, automatic recording systems for all dynamic tests, including unconfined compression test, triaxial compression test, direct shear test and consolidation test were completed.

Around 1975, it became common to use triaxial compression test to obtain a parameter based on the effective stress in the evaluation of soil behavior. In the old system in which analog data was obtained using a 2 channels X-Y recorder, not only was it an extremely complex operation to organize data based on effective stress, but considerable error was also involved. Consequently, we concentrated on realizing advances in the automatic collectivized recording of data from the triaxial compression test as well as equipment to process this data. First, we perfected an on-line system coordinating a bank of ten triaxial cells, by using a Hewlett-Packard 1000 computer. Next, a microprocessor was used to develop an off-line system, composed of a bank of 4 triaxial cells.

At present, a bank of 18 triaxial apparatus are in use in OYO's soil testing laboratory.

We will describe the data processing system that we have developed for the triaxial test and our future plans for further automation as follows.

2 OVERVIEW OF OYO'S 4 CELLS TRIAXIAL APPARATUS

The advantages of the triaxial compression test are that are the specimen may be subjected to shear stress for long periods, it is easy to conduct the test under anisotropic stress and furthermore, testing can be carried out under conditions close to ideal. The factors behind this include the fact that the measuring system is completely automated, all triaxial cells are adjustable for anisotropic stress, there are separate compression and consolidation units for each

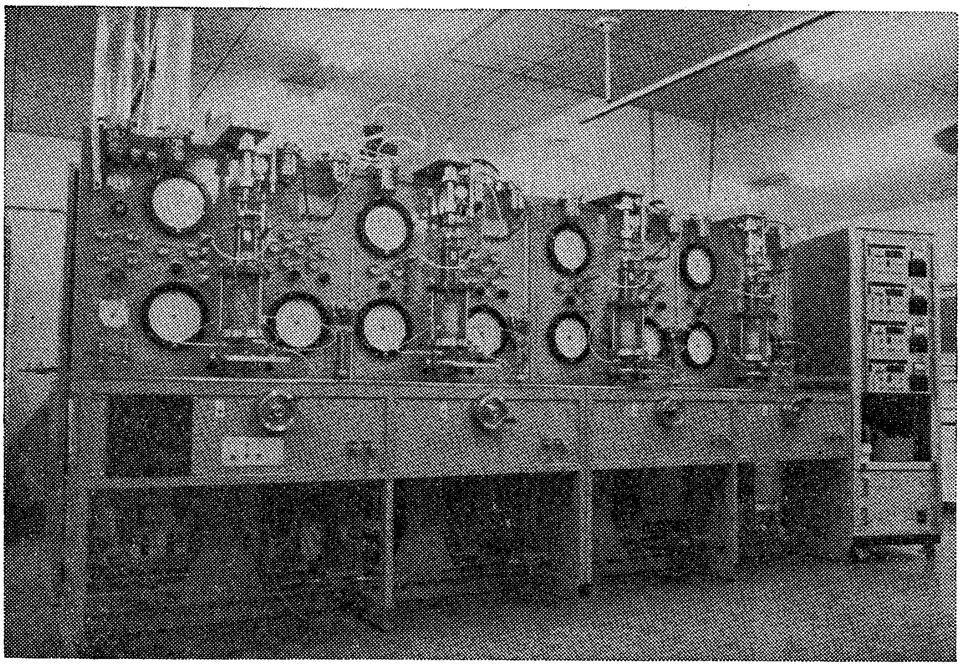

Photo 1 OYO's 4 cells triaxial apparatus

triaxial cell, and completely deaired water is used and this deaired state is maintained when water is forced into the cell. The testing apparatus is divided into sets of 4 cells so that testing can be carried out using 4 different types of pressure. At present, OYO's soil testing laboratory has four 4-set systems and two 1-set systems (Photo 1).

2.1 Triaxial Cell

As shown in Figure 1, there are two types of triaxial cells. With the cell on the left type A, the entire apparatus may be separated by loosening the two outer rods on either side of the acrylic cell wall. With the cell on the right type B, only the cell wall itself is removable when the outer rods are loosened. Both types of cell use a bellowphragm cylinder driven by a piston to apply stress to the specimen.

The B type triaxial cell is generally used in isotropic consolidation testing. Its procedure is simpler of the two types.

Because the piston and the specimen cap may be connected together with the A type triaxial cell, this type is used when sand samples, which easily crumble, are used in anisotropic

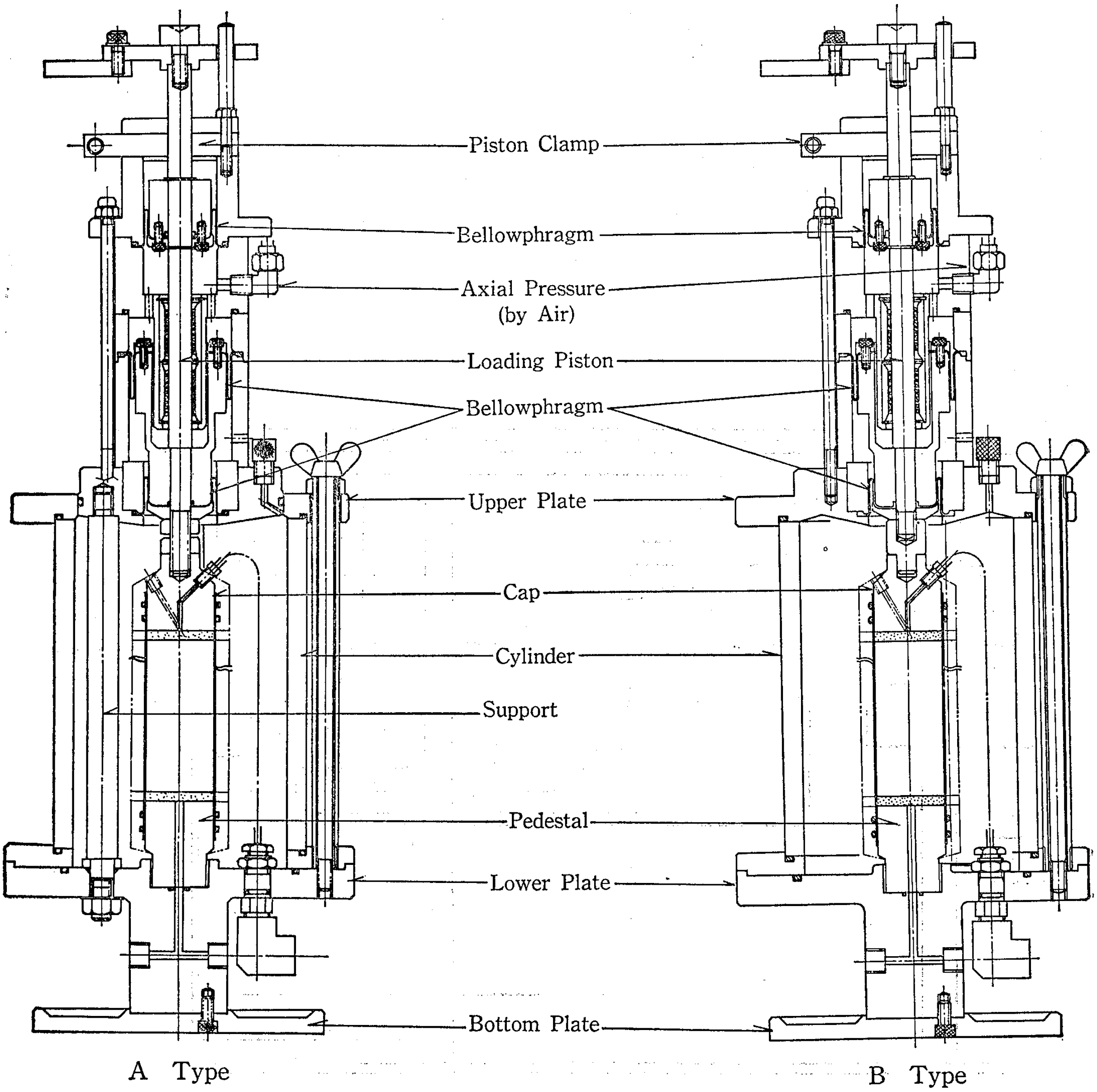

Fig. 1 Scheme of triaxial cell

stress condition.

In addition, by using different pedestals, specimen sizes of $\phi35\times80$mm or $\phi50\times100$ mm may be tested.

2.2 Compression Equipment

Compression equipment consists of a transmission parts (jack) and motor. There is a separate jack for each compression apparatus, while the driven mechanism is linked to 4 compression units by a chain, and is controlled by a single motor and a transmission.

The ballscrew jack used by the apparatus is capable of exerting a maximum load of 500 kgf.

The driven mechanism used a synchronous motor capable of 32 gear ratios giving compression speeds from 0.00044 to 5.0mm/min. The screw jack has an electromagnetic clutch, allowing pushbutton operation.

2.3 Air and Water Systems

Figure 2 shows a schematic diagram of the air and water supply system. Source of pressure in the system is achieved by air compression equipment. The compressor constantly maintains a pressure within the tank of 12.0 to 14.0 kgf/cm^2. The first-stage pressure regulator for each regulator unit is set to deliver a uniform pressure of 11.0 kgf/cm^2. In addition, fine adjustment regulator of second stage permit highly accurate adjustment of confining pressure, axial pressure and back pressure.

To measure each pressure value, a high precision pressure meter (with 0.25% F.S urdon tube guage) used a 10 kgf/cm^2 for confining pressure and axial pressure, a 6 kgf/cm^2 pressure guage for back pressure.

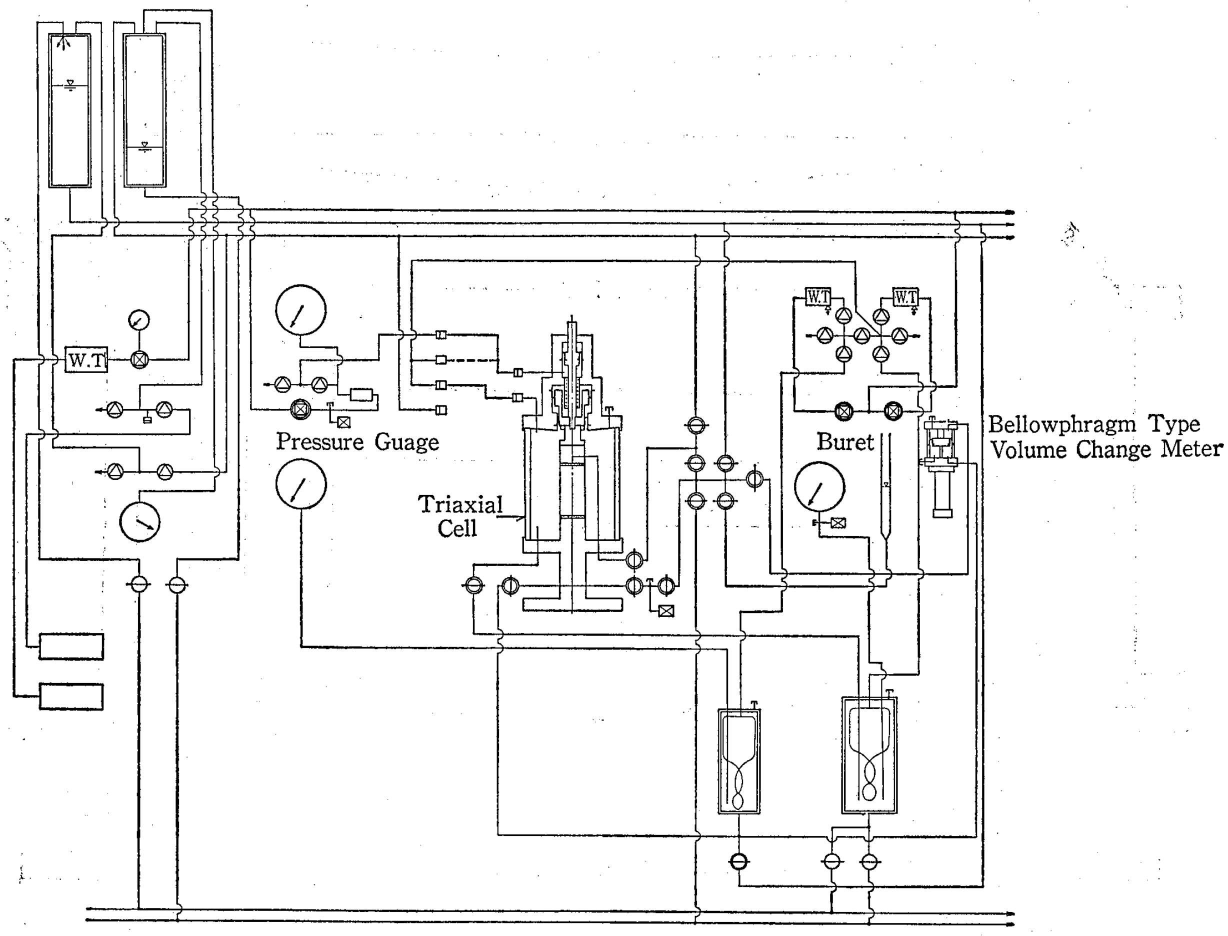

Fig. 2 Air and water system

As a matter of course, in consideration of the fact that water used in experiments over a long period of time has an influence on test results, deaired water is used. In addition, when pressure is applied to this deaired water, in order to prevent the introduction of air, a balloon apparatus is used.

3 AUTOMATED SYSTEMS

3.1 On-Line System

As shown in the Figure 3 the system is mainly connected with a Hewlett-Packard 1000 computer. Basically, the system consists of a measuring system and a computing system (Photos 2 and 3).

The measuring system consists of displacement detectors, signal conditioners, scanners, AD converters, HP-IB terminals and a central processing unit. In order to check for troubles arising during measurement, a digital volt meter for setting initial voltage values and a terminal that permits monitoring of analog data records are installed. Measurement is conducted by an order from the CPU, which has a measurement program. The scanners are put into operation via the HP-IB terminals and data sampling of analog output voltage from the signal conditioner take place, this voltage is subjected to A/D conversion and enters a disk memory. Because the Hewlett-Packard 1000 computer uses real time programming, a number of different types of experiments can be carried out at the same time.

Experimental data is recalled from the disk memory and this is subject to analysis. The results are printed out on a line printer, at the same time, a digital X-Y protter is used to produce graphs showing stress-strain, strain-pore water pressure, strain-pore water pressure coefficient and strain-principal stress ratio relationships as well as stress path according to a given format. These calculations and plotting of graphs may also be carried out during measurement. In addition, data may be stored in the disk memory if necessary.

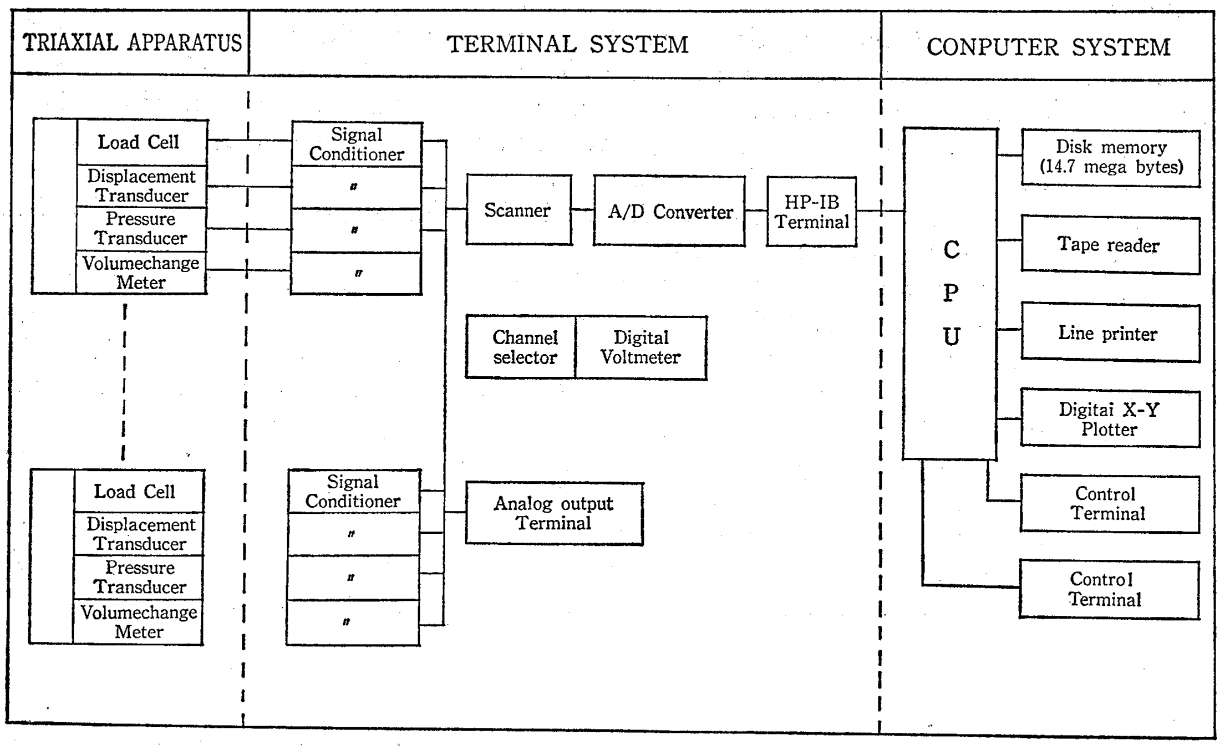

Fig. 3 On-line system

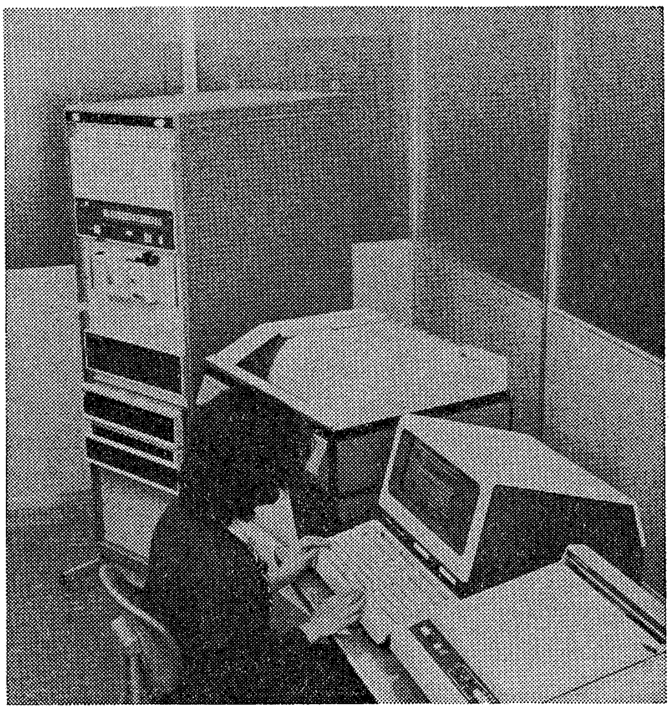

Photo 2 Hewlett-Packard 1000 computer system

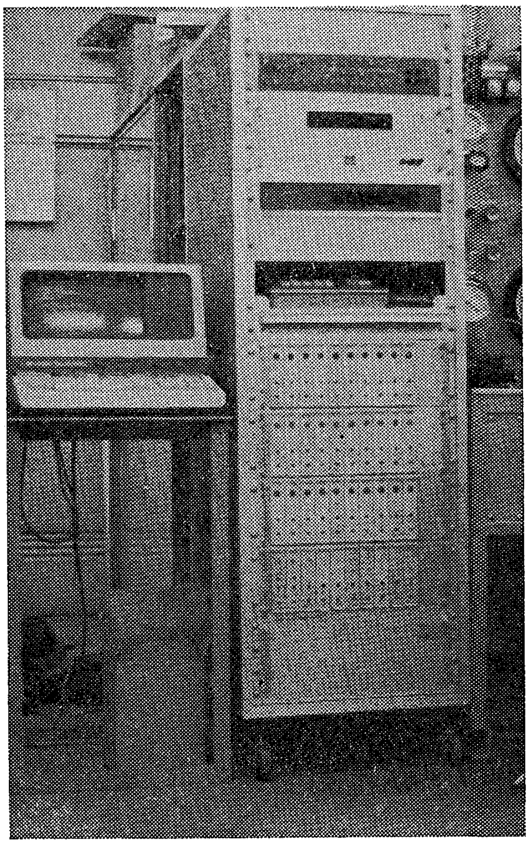

Photo 3 Terminals of the on-line system

3.2 Off-Line System

On the basis of our experience in the developing of the above described on line system, we next proceeded to apply the more flexible, compact and reliable off-line system. At present, 4 cells triaxial compression apparatus, consisting of 2 sets for a total of 8 cells are now in use. By changing the measuring programs, this system may be used for in situ load testing as well as for laboratory consolidation testing.

As shown in the block diagram in Figure 4, the off-line system does not differ fundamentally from the on-line system (Photo 4).

The off-line system is capable of the 6 different kinds of measuring programs shown in Table 1. First, the measurement timing sequence of the program is synchronized against a master clock. When measurement begins, the scanner is put into operation. A/D conversion of data is conducted and digital voltage values are stored in the core memory and at the same time, an X-Y recorder may be connected to an analog terminal to produce records. In addition, because the system has a backup power supply, there is no loss of data if a power failure occurs. If a power failure does occur, the data is stored and measurement continues after power is restored. Data gathered by this system is transferred to punched tape and processed using separate processing equipment (at present, a Hewlett-Packard 1000 computer). As mentioned above, analysis of the data is carried out and graphs, etc. are produced.

4 DETECTORS

It goes without saying that date obtained from experiments is greatly influenced by the precision of the detector used. When output voltage of the detector is low, and amplifica-

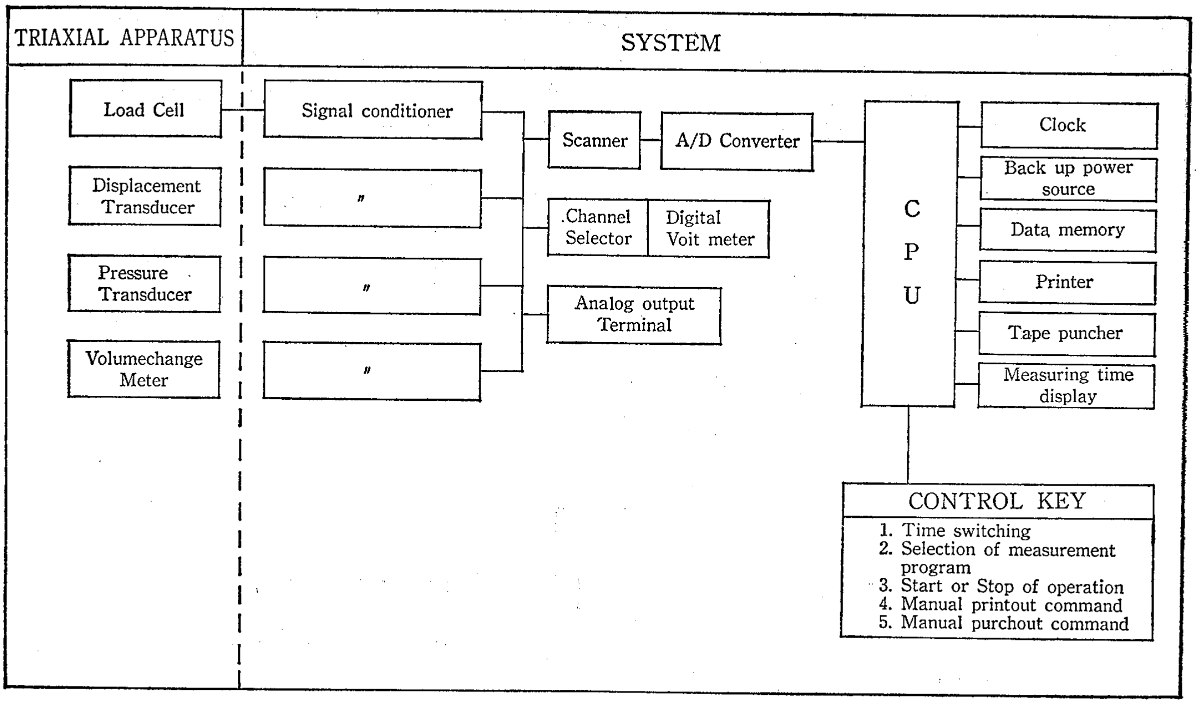

Fig. 4 Off-line system

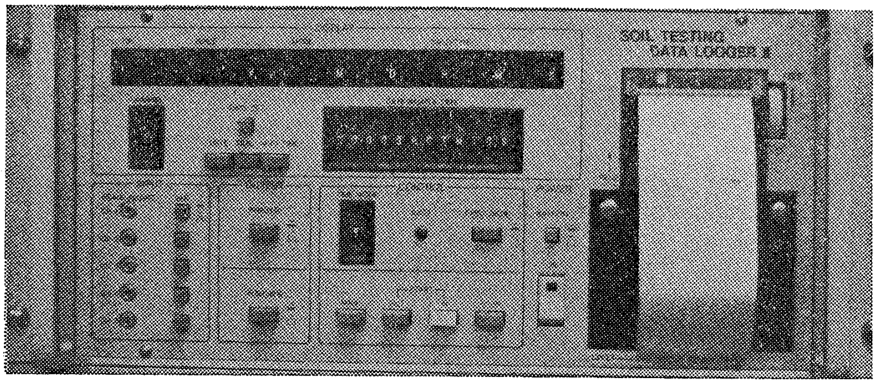

Photo 4 Off-line system

Table 1 Types of measuring programs and timing sequences

No. of measurements / Program No.	20	10	15	55	Total No. measurements
1	3 sec	6 sec	12 sec	15 sec	100
2	30 〃	60 〃	60 〃	150 〃	100
3	300 〃	600 〃	1200 〃	1500 〃	100
4	5 min	100 min	200 min	250 min	100
5($\sqrt{t}$)	2, 4, 8, 15, 30sec, 1, 2, 4, 6, 9, 12, 16, 20, 25, 36, 60min, then, 60min intervals thereafter				100
6(optional)	1 sec to 99 day				100

tion is carried out, the precision of the amplifier also has considerable effect on results. Thus, in designing our triaxial compression apparatus, we have carefully taken these facts into consideration. Figure 5 shows the various detectors used in OYO's triaxial compression apparatus.

4.1 Characteristics of Detectors and Electrical Specifications

○ Stress Meter

A wire strain guage type load cell is used to measure stress. In order to increase accuracy of test results, normally capacities of 100 to 200 or 500 kgf are selected in accordance with soil strength. Sometimes for very soft soil, 50 kgf capacity is also used. Table 2 shows the electrical specifications of this load cell (Photo 5).

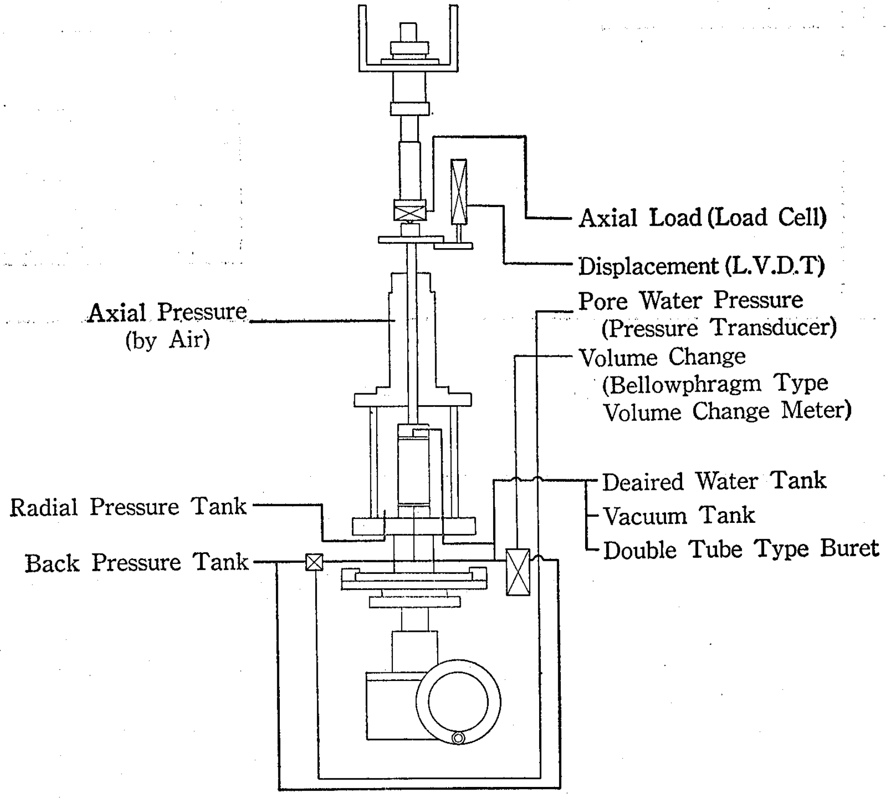

Fig. 5 Scheme of triaxial apparatus

Table 2 Electrical specifications of load cell

Item \ Capacity		50, 100, 200, 500 kgf
Output voltage sensitivity	mV/V	2.0
Input voltage	V	12
Non-linearity	% F.S	±0.15
Hysteresis	% F.S	±0.1
Repeatability	% F.S	±0.05
Temperature effect on zero balance	% F.S/°C	±0.005
Temperature effect on output	% F.S/°C	±0.01

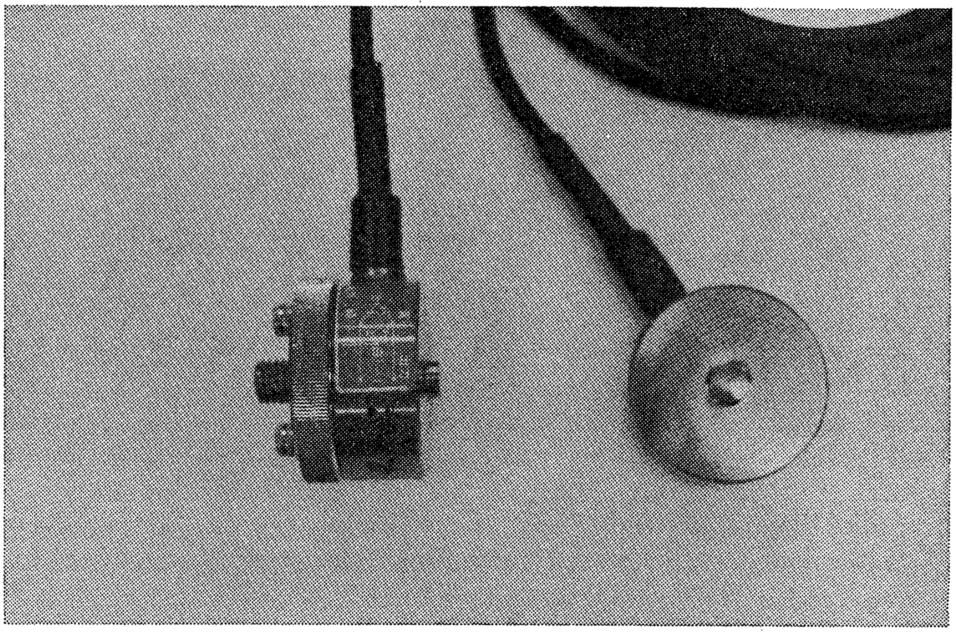

Photo 5 Load cell

o Displacement Meter

A differential transducer is used for measurement of strain(expressed as displacement in centimeters). Previously, an alternating current differential transducer had been used for measurment, which required a very complex signal conditioner. However, because the differential transducer now in use features an oscillograph, a rectifier and amplifier, it is possible to use a direct current so that output is also a direct current. In addition, output voltage is high-300 mV/V. As a result of all these features, the signal conditioner has been greatly simplified. Table 3 shows the specifications of the transducer (Photo 6).

o Pore Water Pressure Meter

A pressure transducer with a semi-comductor guage is used for measurement of pore

Table 3 Electrical specifications of differential transducer

Measuring length	mm	0 to 30
Output voltage sensitivity	mV/V	300
Input voltage	V	3 to 10 DC
Non-linearity	% F.S	±0.1
Temperature effect on output	% F.S/°C	±0.02

Table 4 Electrical specifications of pressure transducer

Accuracy	% F.S	Within 1%
Input voltage		5 V DC or AC
output signal	mV F.S	100±1%

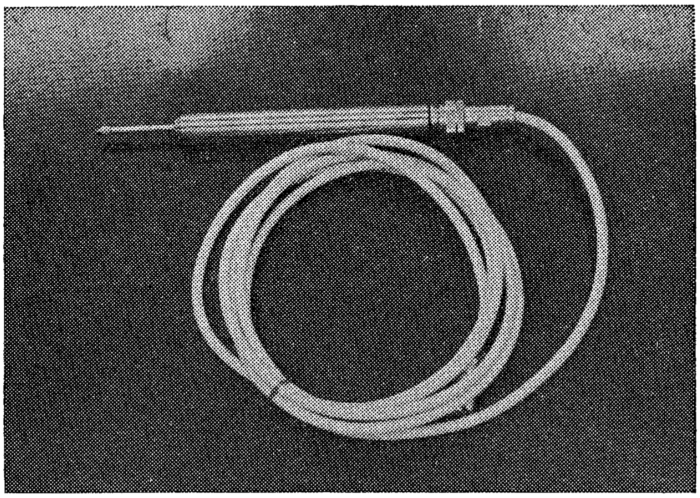

Photo 6 Differential transducer

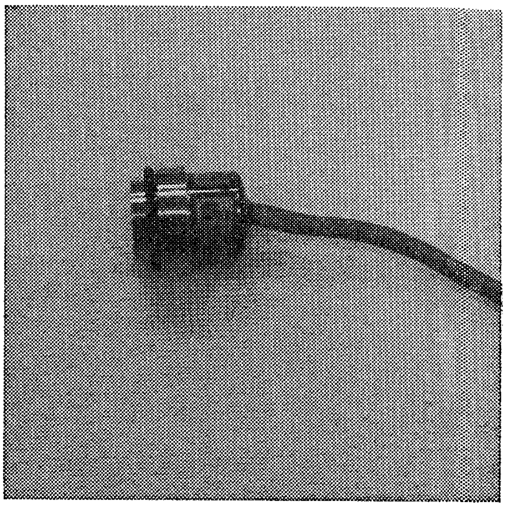

Photo 7 Pressure transducer

water pressure. The diapham of the pressure transducer has extremely little deformation. In addition, output voltage is approximately ten times that of wire strain guage type transducers (Photo 7).

o Volume Change Meter

Automation of measurement of volume change has lagged behind most of all in efforts to modernize the triaxial compression test. For measuring volume change, there are a variety of systems which use photoelectric tubes, float type meter with gap sinsors and differential pressure meters, etc. Each system has its advantages and disadvantages.

For example, when measuring with pressure differential volume change meter at low range of confining stress, discharged water head affect a considerable pressure change of confining stress. Then this meter is suitable to the high stress condition of confining stress.

With float type or buret-equipped volume change meters, there is a disadvantage in that a rate of volume change causes a significant difference to reading value because a shape of meniscus is changed in the state of rise and down of water surface in reading tube. Also the fact that those volume change meters are expensive is a significant factor. The use of a few of these meters in the automation of the triaxial apparatus is effective, but the use of a dozen mote in automation can easily become economically impractical. Since we developed our triaxial compression apparatus in 1977, we have continued to improve the system, making it economical and at the same accurate with the use of volume change meters. Our first volume change meter is shown in Figure 6 (Photo 8). In this device, water from the specimen is collected in a tank by means of a glass tube. A spring scale with a differential transducer weighs this water Figure 7 shows data obtained by using this apparatus. We see that hysterisis produced by friction with the centralizing during supply or drainage of water was as much as 1 ml, making the device far too inaccurate for use.

Next, the volume change meter shown in Figure 8 (Photo 9) was developed. This device employs a 2-stage cylinder. The drainage water line from the specimen leads to the top of the cylinder. A bellowphragm piston is located immediately below the bottom of the cylinder. Its movement in accordance with drainage or supply of water is detected by a differential transducer. Unfortunately, with this apparatus, an o-ring must be used to seal the core shaft, which drives the differential transducer, if the transducer is not the pressure resistance type. However, the use of this o-ring has an undesirable effect on experimental results. Consequently, a differential transducer capable of withstanding 100 kgf/cm^2 without admitting water is employed.

Another problem that had to be dealt with concerned the bellowphragm. Generally, bellowphragm use nylon mesh to increase tensile strength. However, it became clear that this mesh decreased rolling action of the bellowphragm, having an undesirable influence on hysterisis of the volume change meter. Ideally, the difference in the pressure between the cylinder and piston should be low, and this difference in the pressure should be constant. Thus, a very thin, meshless bellowphragm of only 0.5mm with sperior rolling action was employed.

Because this bellowphragm is very soft, a centralizer is set at one end of the cylinder to stabilize its movement. Also, because a slight difference in the pressure between the two cylinders aids bellowphragm cylinder stability, the volume change meter presently being used is adjusted for a difference in the pressure of 0.2 kgf/cm^2. When measurements are conducted,

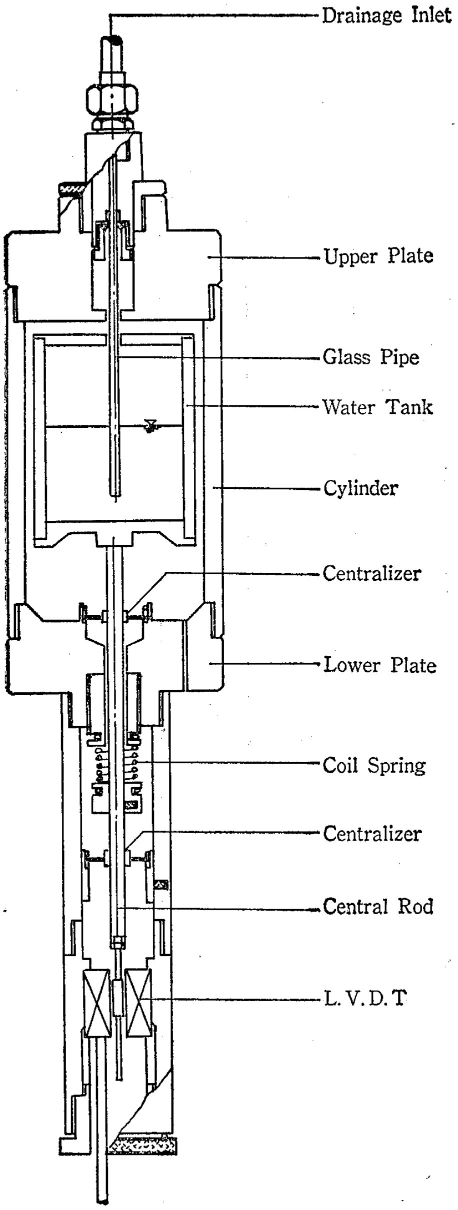

Fig. 6 Scheme of spring type volume change meter

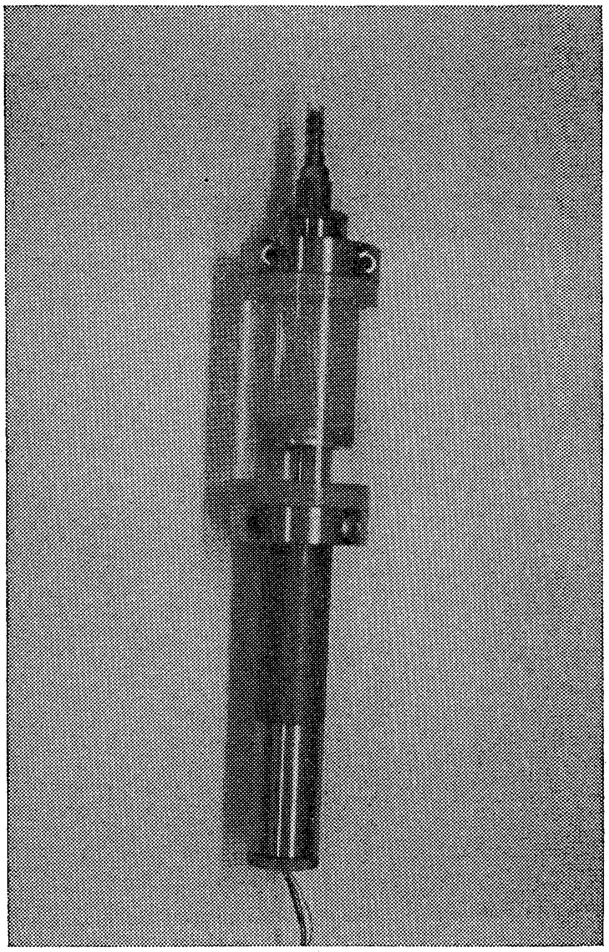

Photo 8 Spring type volume change meter

measuring minute pressures in which this difference would became a problem, back pressure that cancels the cylinder pressure is added.

The differential transducer used in this volume change meter has the same electrical specifications as that used in an axial displacement meter.

4.2 Signal Conditioner

The signal conditioner controls input voltage and output voltage to the load cell, differential transducer, pressure transducer and volume change meter. Along with the accuracy of these various types of detectors, a very important factor determining accuracy of test results is the stability of the signal conditioner. In order to minimize human error and errors in the signal conditioner, all zero settings are done at the stage of calculation. Consequently, recorded values are all actual output voltage values from signal conditioner. However, in order to make monitoring easier for the personnel carrying out the experiments, all output voltage from each type of detector is made uniform and the various actual values are later determined by simple calculation. For the load cell output voltage is corrected to 2000mV F.S, the displacement meter(differential transducer) to 3000mV/30mm, the pore water pressure meter

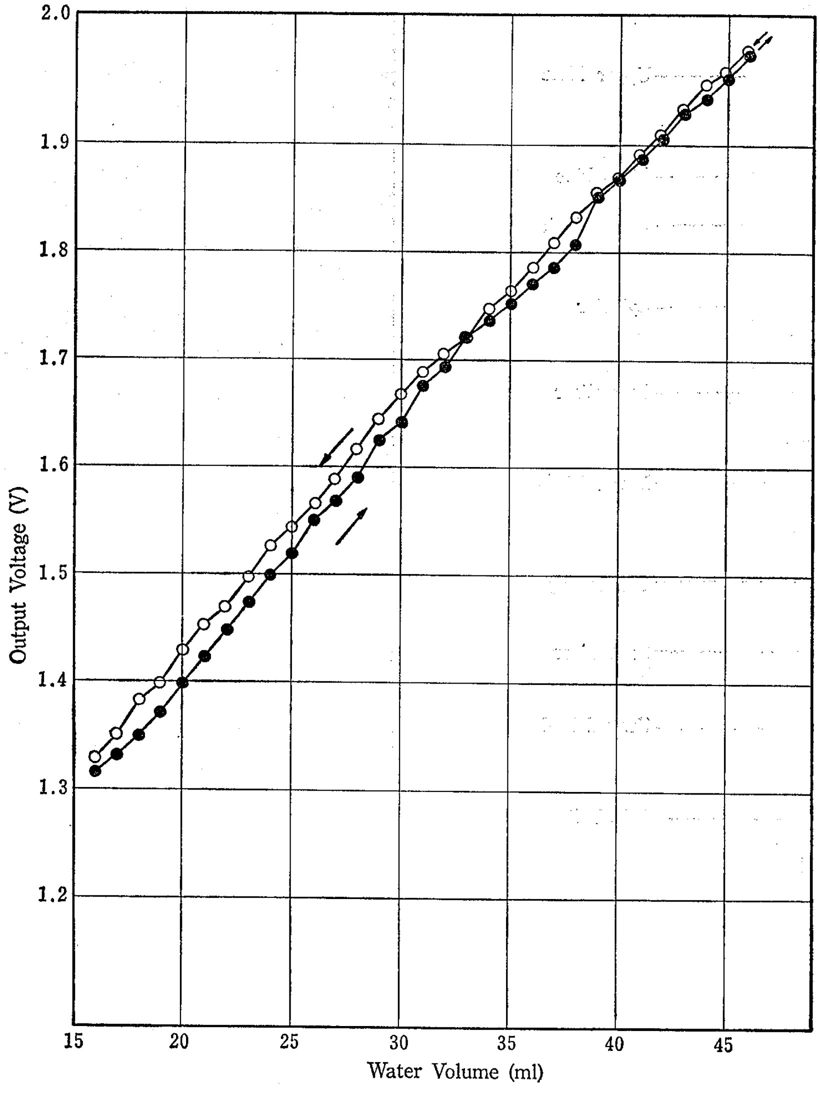

Fig. 7 Calibrating results of spring type volume change meter

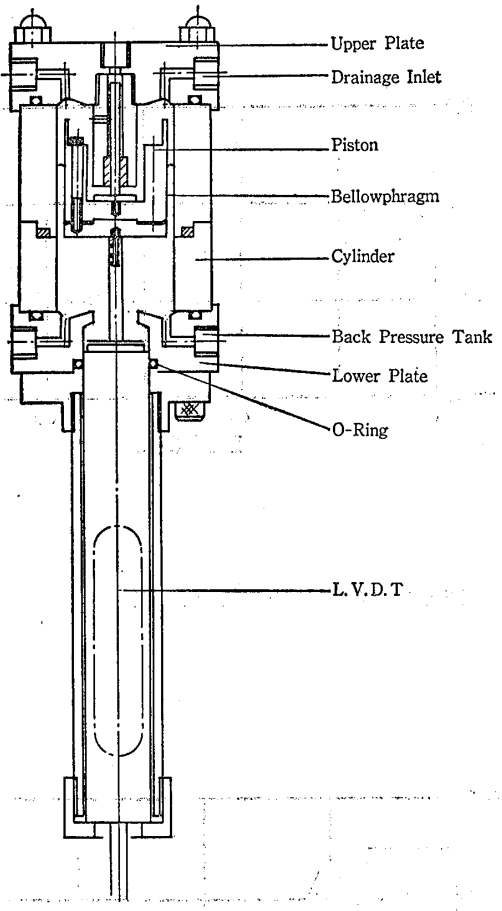

Fig. 8 Scheme of bellowphragm type volume change meter

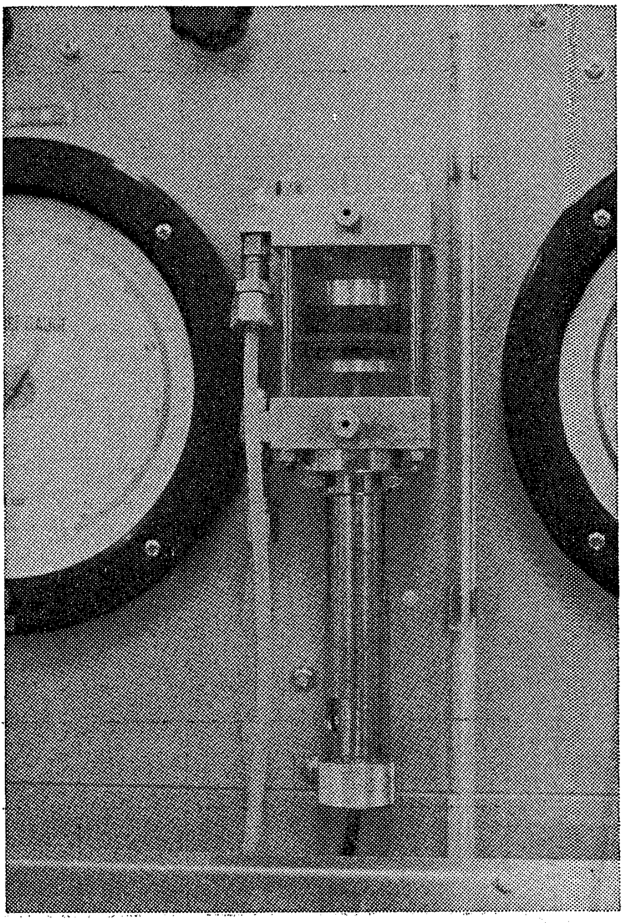

Photo 9 Bellowphragm type volume change meter

(pressure transducer) to 3000mV/6 kgf/cm^2 and the volume change meter(differential transducer) to 3000mV/30ml.

5 Performance Testing

It goes without saying that our triaxial compression apparatus benefits greatly from the high accuracy and resolution of the detectors used. However, the overall performance is the system is also greatly determined by the signal conditioner and the A/D converter as well as the detectors. Because the A/D converter is the final step in the system, the digital values it produces may be used to guage the overall performance of the system.

Thus, the digital values from the A/D converter are used as a basis for judging performance of the system in the test described below. Non-linearity of the test results is seen, for example, with the load cell as maximum deviation, which is expressed as a percentage in relation to rated output. This deviation is found by repeatedly finding the correction curve for the curve between output without a load and rated output when there is a load.

◦ Load cell

The load cell is calibrated by using a 500 kgf capacity calibrator and progressively increasing or decreasing the load on the cell and reading off the digital values for each stage. Figure 9 shows the relationship between load and digital values. Figure 10 shows the non-linearity determined from Figure 9. It was found that the load cell being used as a non-lin-

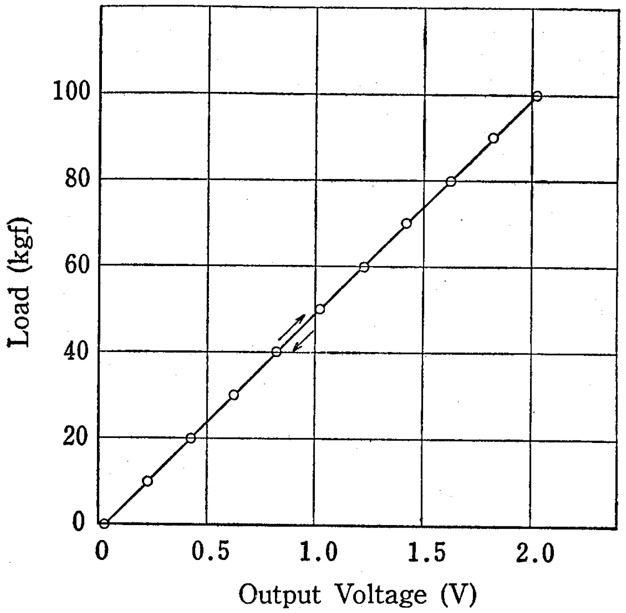

Fig. 9 Calibrating results of load cell

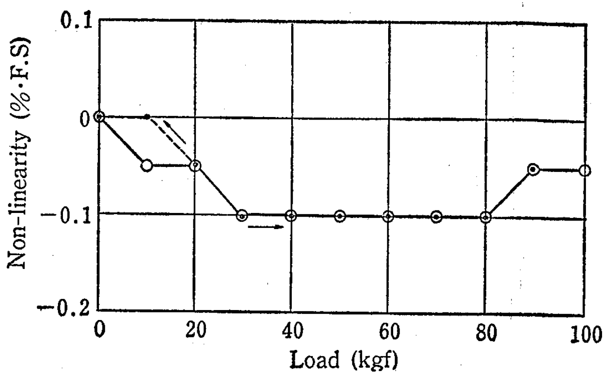

Fig. 10 Accuracy of load cell

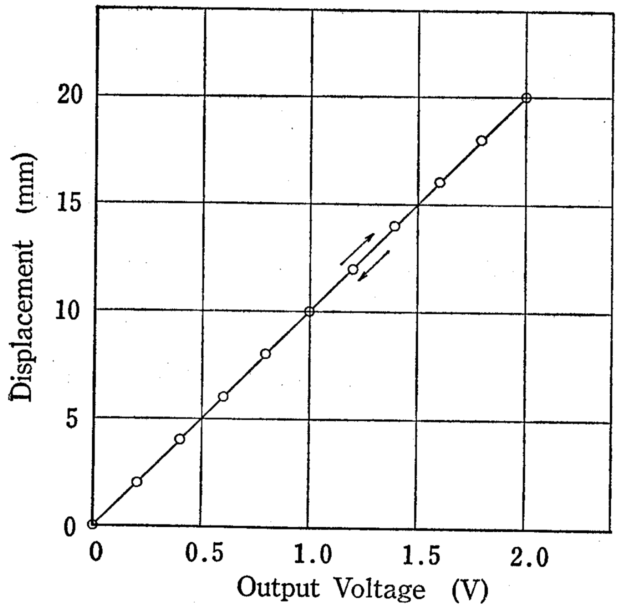

Fig. 11 Calibrating results of displacement transducer (L. V. D. T)

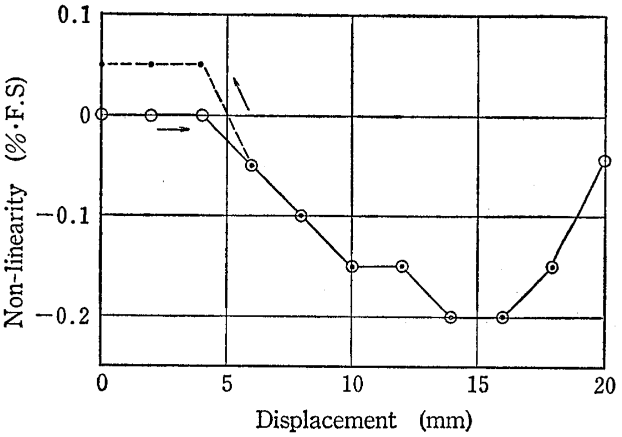

Fig. 12 Accuracy of displacement transducer (L. V. D. T)

earity of not more than −0.1% F.S during both loading and unloading. Hysterisis is approximately 0.05% F.S.

◦ Desplacement Meter

Calibration of the displacement meter is done by setting a dial guage testor (resolution; 1/1000mm) to the differential transducer and reading off the digital values for displacement of the dial guage testor. While the amount of displacement measured by the differential transducer is 30 mm, the dial guage testor is only capable of detecting displacements of up to 20mm. So calibration of only 0 to 20mm is possible. Figure 11 shows the relationship between displacement and digital values. Figure 12 shows non-linearity. Thus, this differential

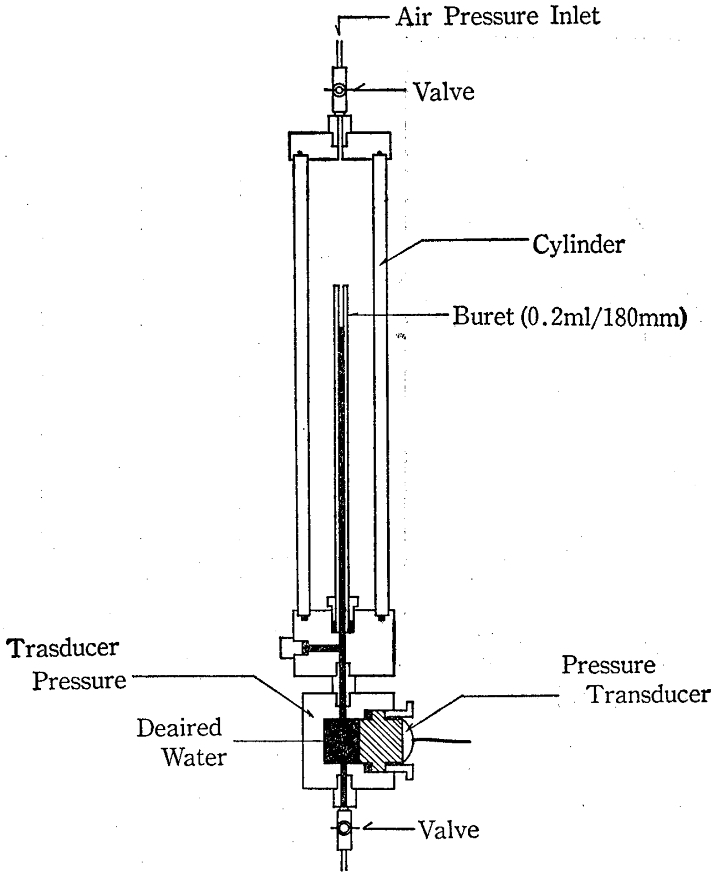

Fig. 13 Scheme of measuring apparatus of volume change at diaphragm of pressure transducer

transducer has a non-linearity value of between +0.05 to −0.2% F.S, while hysterisis is 0.05 % F.S.

◦ Pore Water Pressure Meter

It is desirable that diaphragm deformation amount be small in the pressure transducer used in measuring pore water pressure. Deformation of the diaphragm in the apparatus shown in Figure 13 was measured. The device consists of a double tube type volume change meter and a block with a pressure transducer. Buret of a 0.2ml capacity and 180mm length is located inside the inner tube to measure minute deformation and volume change of the diaphragm. Water in the buret and the block is deaired water.

The calibration consists of opening the air pressure from inlet valve, measuring the air pressure and water level in the buret under air pressure. The actual transducer used in the system was compared with results from measurements of deformation with dummy transducers of the same type. The results are shown in Figure 14 with the relationship between amount of volume change and pressure. Figure 15 shows the relationship between amount of volume change and capacity of pressure transducer at full scall. From the figure it can be seen that for all transducers amount of volume change at full scall is only a small 9×10^{-3}ml, a negligible value.

Next, in checking pore water pressure, a pressure transducer and bourdon tube guage (0.25% F.S) is installed to pressure controling equipment, and the values registered by each as pressure are added in stages and read off. These results are shown as the relationship between output voltage and pressure in Figure 16. Figure 17 shows non-linearity. From these figures it can be seen that the pressure transducer used to measure pore water pressure has a non-linearity of −0.34% F.S to 0.03% F.S and hysterisis of less than 0.07% F.S.

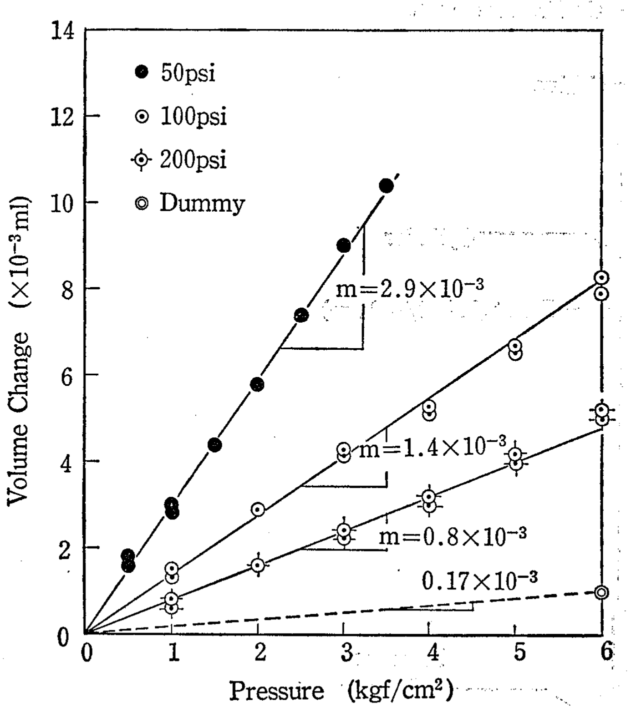

Fig. 14 Calibrating results of volume change at diaphragm of pressure transducer

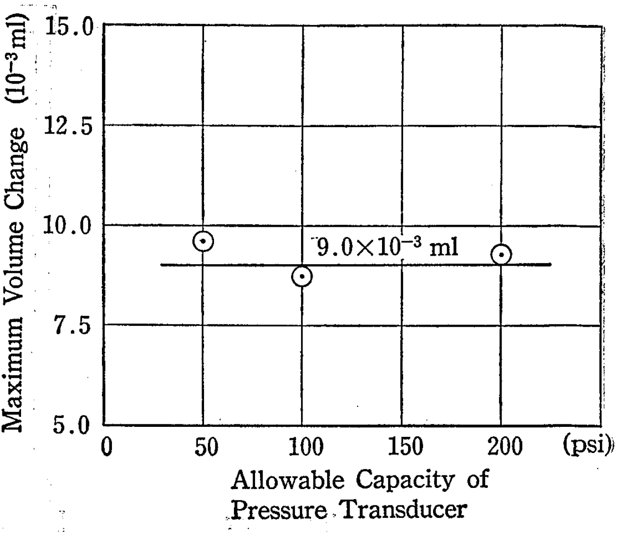

Fig. 15 Maximum volume changes of various diaphragms of pressure transducer at full scale

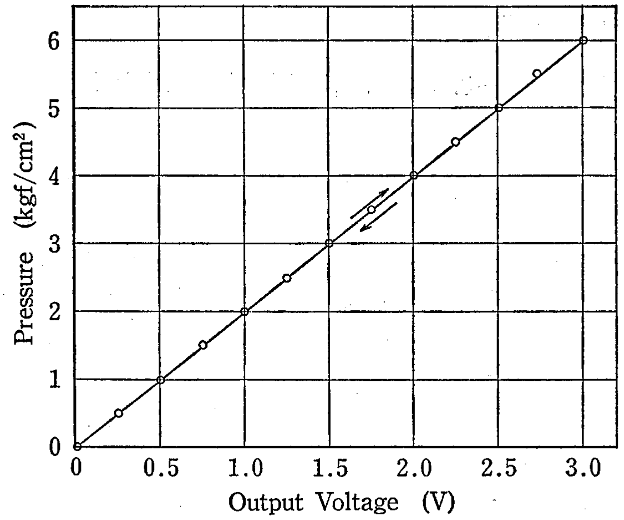

Fig. 16 Calibrating results of pressure transducer

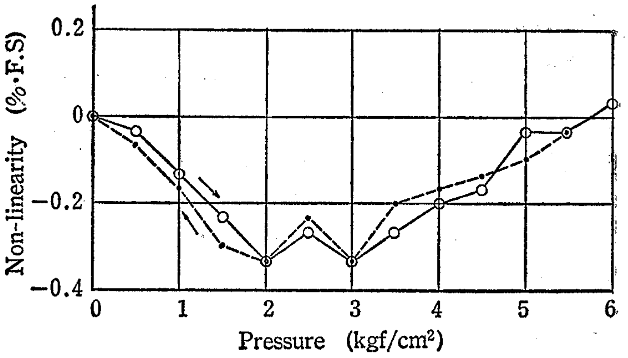

Fig. 17 Accuracy of pressure transducer

○ Bellowphragm Type Volume Change Meter

To calibrate the volume change meter, the double tube type volume change meter (capacity 25ml) shown in Figure 18 was used as a monitor. A difference in the pressure of 0.1 kgf/cm² was added to the back pressure working on both the double tube type volume change meter and the bellowphragm type volume change meter. Then the double tube type volume change meter valve is used to control amount of volume change, while values on scale of buret of the double tube type volume change meter and digital values from the bellowphragm type volume change meter are read off. The results are shown in Figure 19. Figure 20 shows non-linearity. Non-linearity during water drainage is 0.13% F.S, while water is being supplied, it is 0.29% F.S, while the overall range of non-linearity is −0.04 to 0.29% F.S. Hysterisis is 0.29 % F.S, which comes to 0.07ml, indicating a considerable degree of accuracy.

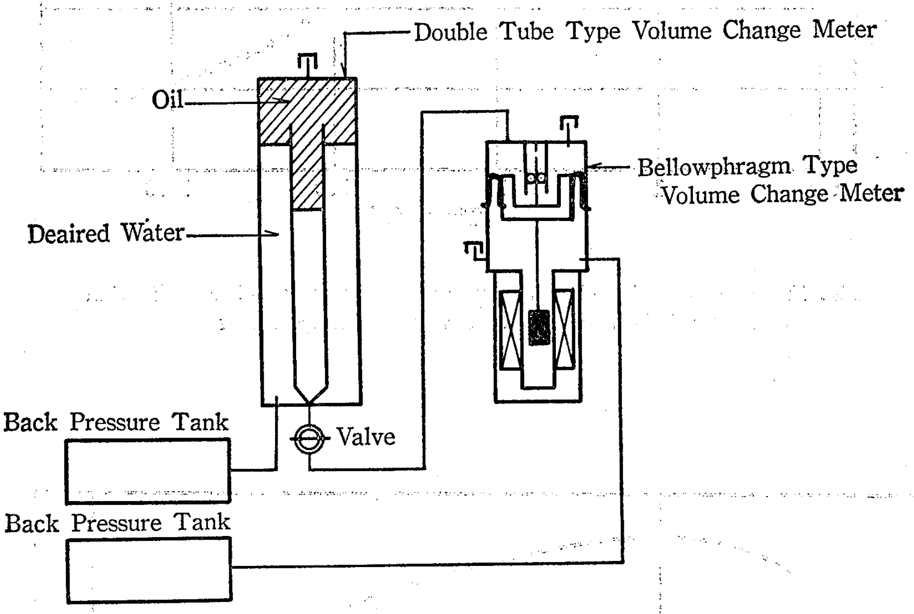

Fig. 18 Scheme of calibrating apparatus of volume change meter

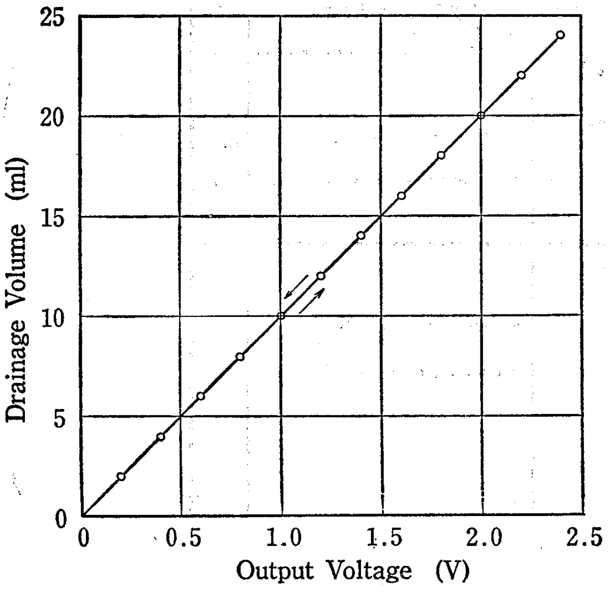

Fig. 19 Calibrating results from bellowphragm type volume change meter

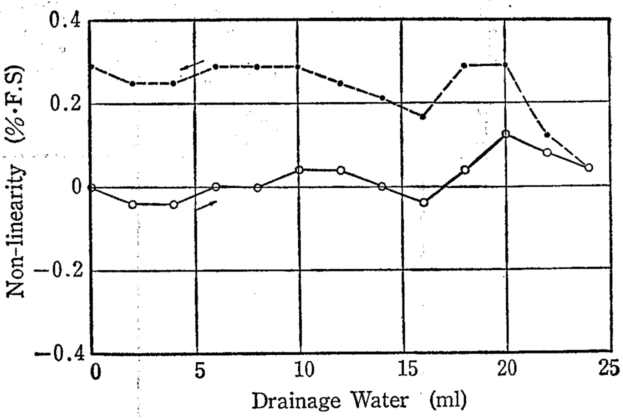

Fig. 20 Accuracy of bellowphragm type volume change meter

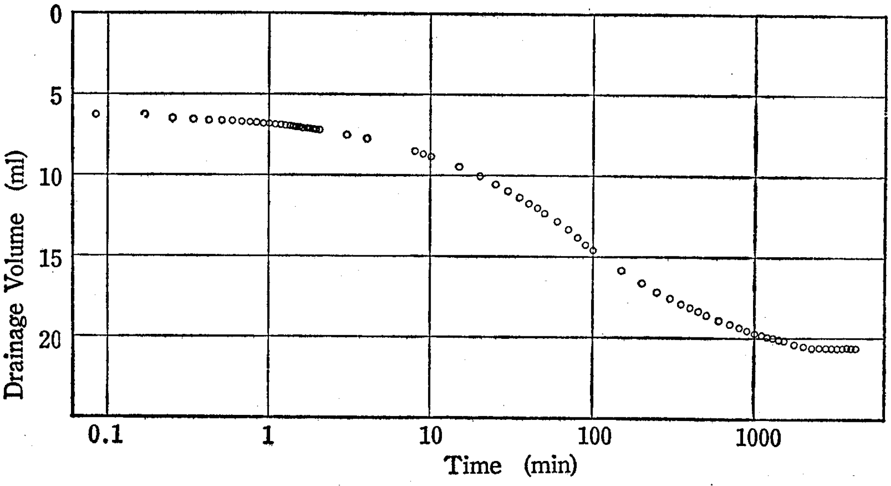

Fig. 21 Record of time-drainage volume during triaxial consolidation using the bellowphragm type volume change meter

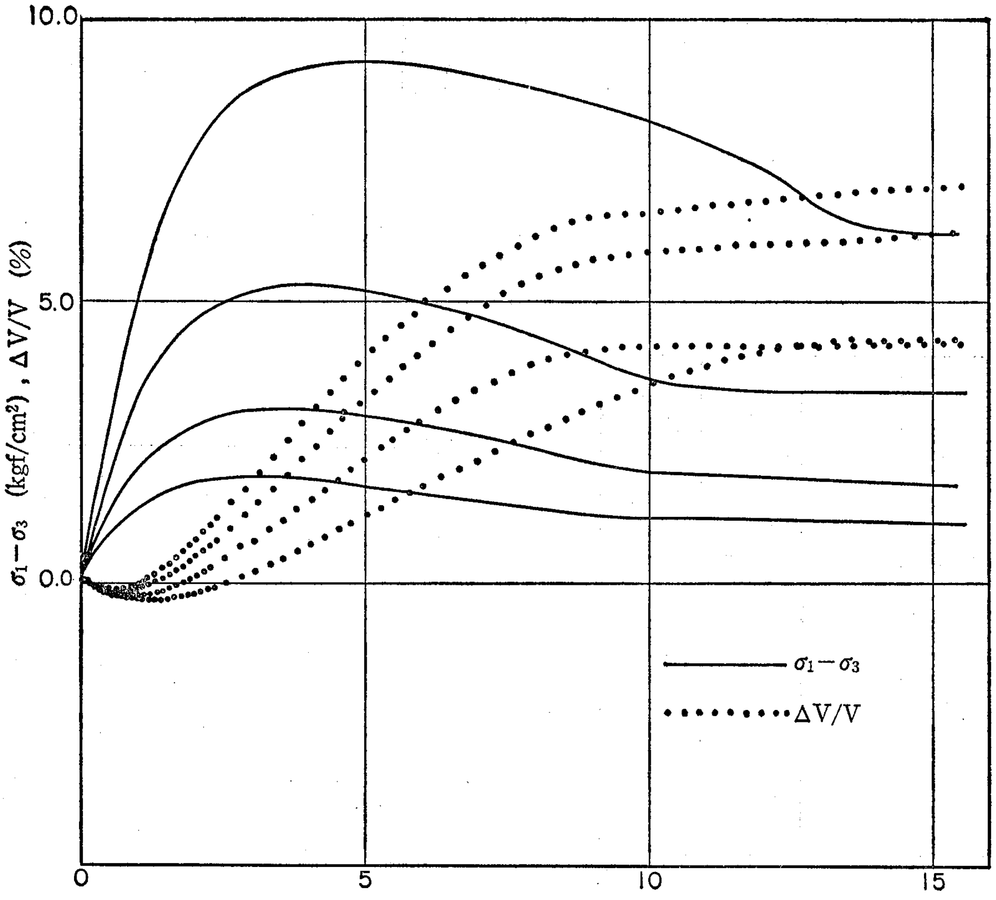

Fig. 22 Records of consolidated-drained triaxial compression test (CD)

6 Example of Test Results

Below is a description of actual data that was taken using OYO's triaxial compression apparatus, including the data processing and the production of graphs using a digital plotter.

Figure 21 was produced by measuring the amount of water drained from $\phi 50 \times 100$mm specimen when subjected to all-round pressure as measured by a bellowphragm type volume change meter. The relationship between these measured results and time is shown. This bellowphragm type volume change meter is used by us for consolidation and shear in triaxial test. As shown in Figure 21, this device is extremely accurate.

In Figure 22 we see curves produced by using a digital plotter to show deviator stress-axial strain and volumetric strain-axial strain, based on the results of drained shear test. Figure 23 was also produced by a digital plotter to show pore water pressure coefficients and principal stress ratio, calculated on the basis of deviator stress and axial strain results obtained by consolidated undrained triaxial test of clay. Figure 24, also produced by the digital plotter, shows stress path. We have automated the process of measurement, calculation and even of plotting. While it is conceivable by automation of methods to determine C′, ϕ' or Cd, ϕd at present, we are now relying on the judgement of testing engineer in determining these strength coefficients.

7 Remarks Concerning the Automated Date Processing System

It has become clear that there are both advantages and disadvantages between the on-line and off-line systems. However, it can be said that both represent significant improvements in the area of reduction of necessary manhours and the improvement of accuracy. With analog type testing apparatus, reading off of graphs as well as calculation was all done by hand, which was of course not only time consuming but less accurate. In comparison to this, the present system represents a major improvement in accuracy and time saving as well. Below, the characteristics of two systems are described.

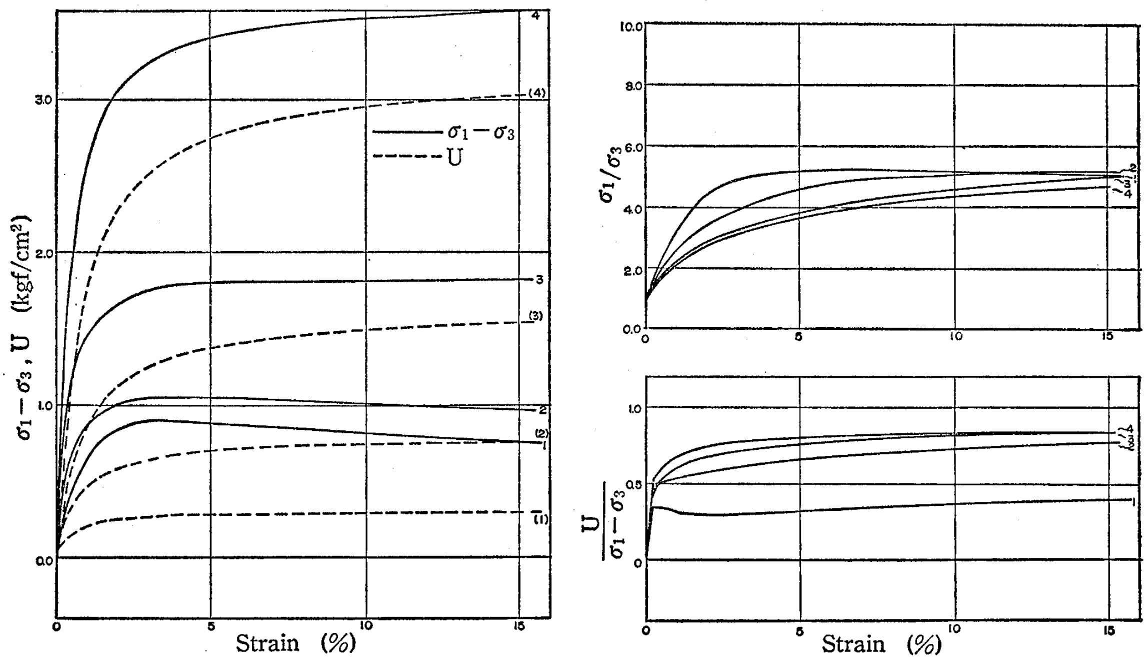

Fig. 23 Records of consolidated-undrained triaxial compression test ($\overline{\text{CU}}$)

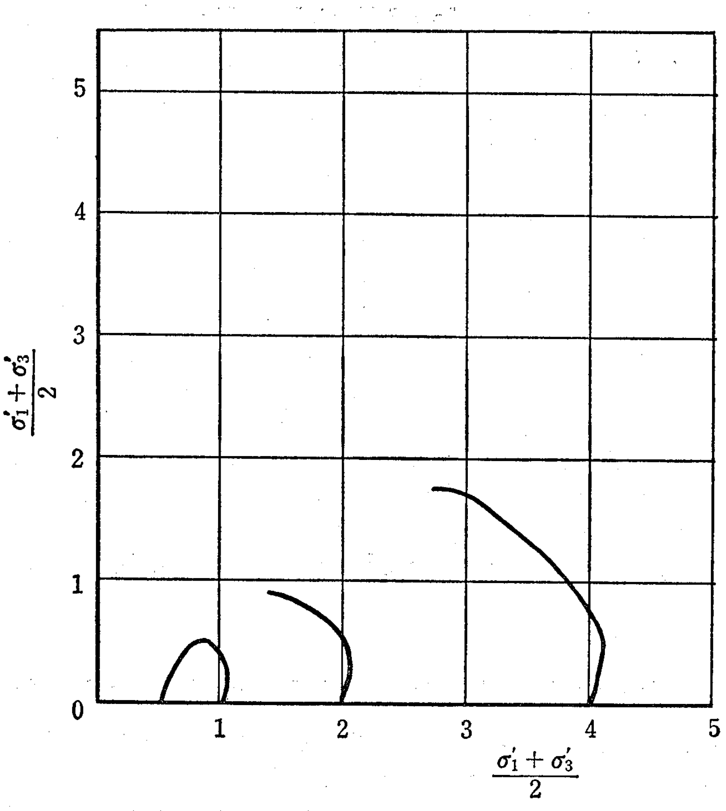

Fig. 24 Stress path

- On-Line System
  (1) The system is not appropriate for small scale operations.
  (2) When difficulties develop in the system, the entire system stops, thus necessitating interruption of measurement, calculation and plotting.
  (3) The system is uneconomical in that it cannot be partially activated. Thus, even if only a single unit is used, the entire system runs.
  (4) Highly experienced personnel are required to operate the system.
  (5) While it is possible to have a backup system for this, as a countermeasure against power failures, this would represent a considerable financial burden.
  (6) It is easy to use component with unnecessarily high accuracy in relation to the overall accuracy of the entire system.
- Off-Line System
  (1) The system is composed of small separate units that may be obtained individually as required.
  (2) The system is composed of easy to use units specifically designed for the necessary data. This can be operated by personnel with no special training.
  (3) Because the system can be kept small, a backup countermeasure against power failures is realtively easy to incorporate.
  (4) The system is not complicated and therefore maintenance is relatively simple.

The above characteristics are based on our observations after several years of experience with both the on-line and off-line systems. Generally speaking, it may be said that off-line system is better suited for automation of the triaxial compression test from the standpoints of economy and ease of use.

Concerning the problem of improvement of measuring accuracy, it could be said that what is needed is selection of detectors with superior stability and linearity characteristics without worrying about unnecessarily high accurate standards of accuracy in other parts of the system.

Although environmental factors are not a major problem in testing carried out over short piriods of time, it does become an area of concern when tests extend over long time periods. For example, the effects of changes in room temperature can have a major effect on detectors and the testing equipment, so that regardless of how accurate the system itself may be, the test results become unreliable. Consequently, we keep both our triaxial testing and consolidation testing laboratories at a uniform temperature of 25 degrees C. ± 1 degree.

8 Afterword

Above is a description of the triaxial compression testing system, its automation and the performance of each of the detectors employed in the system. As mentioned above, an analog system equiped with an X-Y recorder that eliminates necessity for various types of calculations based on measurement data obtained from unconfined compression test and triaxial compression test (UU, CU), and that for this type of testing the analog type system is desirable both from the standpoint of economy and efficiency. However, for triaxial compression test and consolidation test, which involve various types of calculations and plotting of measurement data, the digital system is desirable in terms of the automation that becomes possible, the resultant saving of manhours and accuracy obtained. In the future it can be seen that there will be more and more automation of soil testing as well. In this process, not only data processing equipment incorporation of various type of servocontrol circuits such as are used in Ko triaxial consolidation test in order to move closer to ideal complete automation is necessary. We are now at work to actualize this ideal.

However, there are a number of major problems involved that present themselves regardless of quality of equipment used that concern the environment in which the experiments are carried out, quality of the specimen, etc. In addition, even if these conditions can be adequately satisfied, it must not be forgotten that other factors, such as sampling trimming the specimen and other problems in quality control are probably the greatest factors in determining accuracy of test results.

Unquestionably, recent advances in the field of electronics have come to open many possibilities towards the automation of data processing with high standards of accuracy. In order to realize these goals, upgrading of technology for design or triaxial cells and consolidation boxes is required.

We are constantly keeping in mind the fundamental problems in soil testing as we work to effect automation of soil testing, and are attempting to develop well balanced test equipment for the purpose.

OYO 4 連型三軸圧縮試験機の自動化システム

佐藤勝英・堀之内富夫

概要

構造物の長期安定問題及び地盤の変形挙動を解明する上で，有効応力法に基づく三軸圧縮試験結果が用いられるようになって来ている。従来，この試験は，X—Y_1・Y_2 レコーダーを用いたアナログ方式で自記し，その記録を読取って結果の整理を行っていたため，データ整理が極めて繁雑になり，しかも精度の高い結果が得られなかった。我々は，この種の試験の普及に伴い，省力化，処理能力の増大と精度の向上を計ることを目的として，OYO 4 連型三軸圧縮試験機の開発と自動データ集録装置及びデータ処理装置の開発を行った。最初に開発したのは，10連の三軸圧縮試験機とHP1000をCPUとするオンラインシステムのデータ集録装置とデータ処理装置であった。その後，この経験を基にマイクロプロセッサーを用いたオフラインシステムを完成させ，8連の三軸圧縮試験機に採用している。現在，両システムによって18連の三軸圧縮試験機が稼動しているが，いずれも当初の目的を十分満足する働きをしている。

本報告は，このOYO 4 連型三軸圧縮試験機の概要と自動データ集録装置及びデータ処理装置について紹介したものである。

1. OYO 4 連型三軸圧縮試験機

この試験機は，写真—1に示したが，1試料の試験に対し4拘束圧で試験することを考えて4連を1セットとし，1連毎に三軸室，圧密装置及び圧縮装置を備えていること，三軸室は，図—1に示すように，ピストンを介して供試体に異方応力が加えられるベロフラムシリンダーを備えていること，使用している水はすべて脱気水であることが特徴である。図—2には，本試験機の空気及び水系の配管系統図を示した。

2. 自動化システム

最初に開発したのは，写真—2、3のHP1000をCPUとしたオンラインシステムで，そのブロック図を図—3に示した。このシステムによる測定は，測定プログラムによってスキャナーを稼動させ、アナログ出力電圧をサンプリングし、A/D変換した値をディスクメモリーに書き込ませる方式を採用している。試験結果の演算は、演算プログラムによってディスクメモリーからデータを呼び出し、所定の演算を行なわせている。その結果は、ラインプリンターで打出させるとともにデジタルX—Yプロッターで作図させることができる。

このオンラインシステムの経験を基にして汎用性がある小型で安定性の高いオフラインシステムを開発した。そのブロック図を図—4に示したが、システムの構成はオンラインシステムと基本的には変らない。測定は，システムに内蔵された表—1のプログラムによって行われ、そのデータは，コアメモリーに記録し，測定が終了すると自動的に連続して紙テープに出力するようになっている。本システムには，停電対策としてバックアップ電源が内蔵されているので停電時でもデータを保管することができ，回復後には，測定を継続することができる。

3. 検出器

この試験機に使用している検出器は，軸力の測定にロードセル，軸変位はDC型の差動トランス、間隙水圧は半導体歪ケージを用いた圧力変換器、体積変化は，DC型の差動トランスを検出器としたベロフラムシリンダー型の体積変化計である。

これらのロードセル、差動トランス及び圧力変換器の電気的性能を表—2、3、4に示した。

検出器の中で体積変化計が最も自動化が遅れているが，我々は、経済的で取り扱いの容易な、しかも精度の高い体積変化計の研究開発を行ってきた。

最初に開発した体積変化計は，図—6及び写真—8に示すバネバカリ方式の装置であるが，図—7の検定結果でも明らかなようにシャフト等の摩擦によってヒステリシスが大きいため実用化することができなかった。その後，図—8及び写真—9に示すベロフラムシリンダー方式の装置を開発した。この装置は、ピストンの動きを検出する変位計に耐水、耐圧型の差動トランスを使っていることと、ベロフラムにはローリングアクションを良好にするためにメッシュレスで、しかも0.5㎜と非常に薄いものを用い、ヒステリシスの向上を計っていることが特徴である。

4. システムの性能

本システムの性能は，検出器，シグナルコンデショナー及びA/D変換器を介したデジタル値で表わされる。

図―9，10には、軸力用ロードセルの性能試験結果を示した。非直線性は−0.1％F.S以内、ヒステリシスは0.05％F.Sで，いずれも表―2に示したロードセルの公称値より低く，システム性能がよいことを表わしている。

図―11、12には、軸変位用差動トランスの結果を示した。非直線性は＋0.05〜−0.2％F.Sで、ヒステリシスは0.05％F.Sである。

間隙水圧測定に使用する圧力変換器は，受圧面の変形による体積変化の起さないものが望ましい。図―13の装置を使って受圧面の変形量測定を行った。その結果を図―14、15に示したが、使用している圧力変換器は、受圧面の変形に伴う体積変化が9×10^{-3}mℓと極めて少なく，間隙水圧測定に適しているといえよう。この性能試験結果は，図―16，17に示したが、非直線性は−0.34〜0.03％F.Sで、ヒステリシスは0.07％F.Sである。

ベロフラムシリンダー型の体積変化計については、図―19、20に性能試験結果を示した。非直線性は、―0.04〜0.29％F.Sで、ヒステリシスは0.29％F.Sであり、これは、0.07mℓの量であるから極めて高い精度の体積変化計であると云えよう。

5. 試験結果の一例

我々が開発した三軸圧縮試験機と自動化システムで試験した結果の一例を図―21〜24に示した。図―21は，ベロフラムシリンダーを用いて計測した等方圧密時の排水量である。図―22は，砂の排水セン断試験結果をデジタルプロッターで描かせたものである。図―23は，間隙水圧測定を伴う粘土の圧密非排水セン断試験結果であり，図―24は、そのストレスパスであるが、いずれもデジタルプロッターで作図させたものである。

6. 自動化システムに対する考察

我々は，自動化システムを開発して以来，両システムを数年使用している。その経験をもとに両者の特徴を以下に述べる。

○オンラインシステム

1） 小規模のシステムには向かない。
2） システムの1部が故障してもシステム全体を止めることが多く，その時はすべてのデータが消えてしまうため被害が大きい。
3） すべてのシステムが稼動している時はよいが、一部で試験する時でも常に全体が稼動しているので不経済になりやすい。
4） オペレーターは、かなりの熟練が必要である。
5） 停電対策は、かなり大がかりになり、経済性の面から困難である。

○オフラインシステム

1） 必要に応じたシステム構成とすることができるので経済的に優れている。
2） 専用機として使用することが多いため，使い易いものを作ることができ、特に訓練を受けない者でも利用できる利点がある。
3） システムが小型であるから停電対策は比較的容易に行える。
4） 複雑なシステムでないため、メンテナンスが容易である。

上記より，三軸圧縮試験の自動化システムは、一般論としていうと，トラブルの影響が全体に及ばないオフラインシステムの方が優れていると考えている。