An automatic triaxial-oedometer device

Un dispositif automatique triaxial-oedomètre

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SYNOPSIS: This paper introduces a new, automatic, combined triaxial-oedometer device. The equipment is able to run oedometer tests with constant pressure ratio, constant rate of strain and incremental loading test procedures and triaxial tests with consolidated-drained and consolidated-undrained types of test. It also possesses versatile possibilities to monitor the test performance and to present the test results. In the paper the value of the test results gained with the new equipment is discussed based on a series of 52 comparative oedometer tests and finally some statistical data about the efficiency of the new equipment in actual test performance are also given.

1 INTRODUCTION

In spite of the continuously growing importance of the in-situ testing methods the traditional laboratory methods still have an important role in most of the soil investigation projects for instance in reliable determination of shear strength and compressibility properties of soils. At present the tremendous developments made in the field of micro electronics have also made it possible to relieve the greatest shortcomings of the old laboratory testing procedures such as long testing time, big labour consumption etc. So far, there has only been two obstacles which have retarded the development of new powerful laboratory tools fully utilizeing the possibilities provided by the modern technology: the lack of research interest on the side of laboratory equipment developers and the reluctance of abandoning the familiar types of test and test results on the side of the users of the equipment.

One approach to modernize the old laboratory technology has been made in the Tampere University of Technology in Finland. In the first stage of the development work a fully automatic oedometer device was constructed a couple of years ago (Kolisoja et al. 1987). Now the work has been completed by integrateing a triaxial equipment into the oedometer device developed earlier, and thereby a new, automatic laboratory equipment for effective, simultaneous determination of shear strength and compressibility properties of soils has been created. This paper intends to give a short introduction of the new equipment.

2 THE NEW EQUIPMENT

The new equipment incorporates three oedometer units and one triaxial loading frame (figure 1). In each unit the sample deformations are accomplished by stepping motors which are controlled via a control unit by a micro computer. In the measurement of the loads acting on the test samples and the pore water pressures in the samples electronic strain-gage transducers are used. The measurements are collected through a data logger which also operates under the control of the micro computer. The triaxial unit is equiped with a pressure source providing simultaneously three different consolidation pressures. A very sensitive electronic balace is used to measure the volumetric strains of saturated samples in drained triaxial tests. For the purpose of test result presentation a A4-size plotter and a matrix printer are also included into the equipment.

3 CAPABILITIES OF THE EQUIPMENT

In the development work of the new equipment three main targets have been kept in mind:

1. An effective laboratory tool should be created with which tests could be run automatically independent on working hours and with minor effort of the laboratory personel.
2. Maximum versatility should be achieved in performing various types of tests simultaneously.
3. The equipment should be easy enough to use, so that ordinary laboratory personel can handle with it and no special skills on electronics or computer science are needed.

Concerning the versatility of the new device the following oedometer test procedures are available: constant pressure ratio test (CPR test), constant rate of strain test (CRS test) and incremental loading test (IL test), which can be controlled either by the excess pore water pressure measured at the undrained bottom of the sample or by the loading time. In the triaxial unit the conventional consolidated-drained and consolidated-undrained types of test can be run. To ensure the versatile use of the equipment, the control program is developed so that any type of test can be initiated, performed and terminated in an appropriate loading unit entirely independent on other tests which may be goeing on in the other loading units.

Figure 1. The new triaxial-oedometer device; the three oedometer units in the foreground and the triaxial unit at the back.

The performance of the tests with the new equipment is made as easy as possible. In the beginning of the test the sample is prepared in about the same manner as with the traditional oedometer and triaxial devices. Then the sample cell is mounted into the loading frame, the cables of the transducers are connected, the sample data and control terms of the actual test are fed interactively into the micro computer and the test is initiated. Thereafter no other manual operations are needed - the micro computer takes care of the measurements and also adjusts the deformation rates based on the collected data. When the test finally reaches the interruption criteria stated at the beginning of the test, the test results are stored on floppy disks and the most time consuming test result interpretation processes are also performed automatically without precence of the operator. Reportready printouts of the test results can thereafter be produced in a couple of minutes.

During the program run the tests in progress can be monitored by plotting on the screen various graphical curves presenting the actual test stages. In CPR and CRS oedometer tests the load-compression and load-pore water pressure curves, and in IL tests the time-compression curves can be produced. In consolidated-undrained triaxial tests the deformation-load and deformation-pore water pressure curves are available; in drained triaxial tests the deformation-volume change curve replaces the pore water pressure curve of the undrained test.

From the test results numerous different graphical representations can be produced. On the oedometer side the CPR and CRS tests give the curves of relative compression, modulus of compressibility, coefficient of consolidation, pore water pressure and deformation rate as functions of the effective vertical stress acting on the sample. The IL tests can in turn be interpreted in time compression curves of each loading step and in load-compression curve of the whole test. Naturally the compressibility parameters and the preconsolidation pressure σ_p can also be determined from the test results and the various plots can be produced in linear, logarithmic or square root scales.

From the results of undrained triaxial tests the curves of compression-load and compression-pore water pressure can be plotted. In drained tests the compression-volume change curve is gained again instead of the pore water pressure curve. In addition, curves of the same type from several tests can be collected to be plotted on the same plot. Naturally a series of triaxial tests can also be presented in the form of Mohrs circle diagram and stress path representation (figure 2).

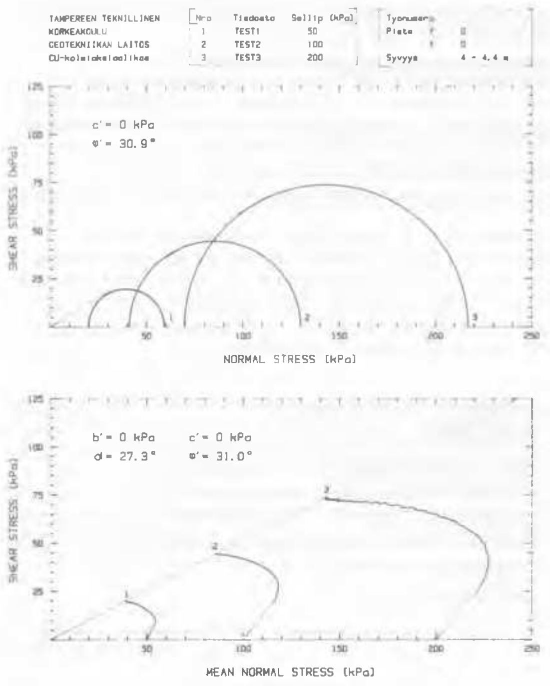

Figure 2. An example of the triaxial test result printouts.

4 EVALUATION OF THE TEST RESULTS

Concerning the triaxial tests the main advatages of the new automatic triaxial-oedometer device are in the ease of operation in test performance: no complex mercury manometers, variable testing rates without any mechanical insatallations, automatic data collection during the tests, versatile plotting facilities from the test results etc. The test procedures themselves are the conventional consolidated-drained and consolidated-undrained types of test, so the few actual test results presented in figure 2 may serve as an example of the serviceability of the triaxial testing unit.

On the contrary, the test results gained with the automatic oedometer device are worth of a bit closer discussion. Based on many earlier investigations (Sällfors 1975, and Janbu et al. 1981 among others) it is well known that the increased testing rate in the new rapid oedometer test procedures has an effect on the value of the preconsolidation pressure determined from the test results. Meantime the compressibility parameters describing the behavior of the soil after passing the preconsolidation pressure are less affected.

The validity of the aforementioned findings was tested in a series of 52 comparative oedometer tests. Of the tests 20 were performed with CPR test procedure, 11 with CRS procedure and 10 with automatic IL procedure. For the sake of comparison one sample from each of the 11 testing levels was also loaded incrementally in traditional oedometer devices by using 24 hours loading steps. All test samples were taken from one hole at depths from 2,0 to 10,3 m. Along the hole the material being tested varied from soft clay to silt, and its water content varied from 137 to 28 per cent.

In the first stage the values of the preconsolidation pressure were determined automatically by using an algorithm which searches mathematical approximations of the load-compression curve to stress ranges below and above the σ_p value, and then determines the preconsolidation pressure as an intersection point of these two approximation curves. However, with most of the IL tests this method proved to be misleading because of the small amount of points representing the load-compression curve. Therefore the curves were plotted on logarithmic scales and and σ_p values were determined by using Casagrandes method.In CPR and CRS tests it proved to give almoast identical values compared to the mathematical method. The σ_p values thus determined are presented in figure 3.

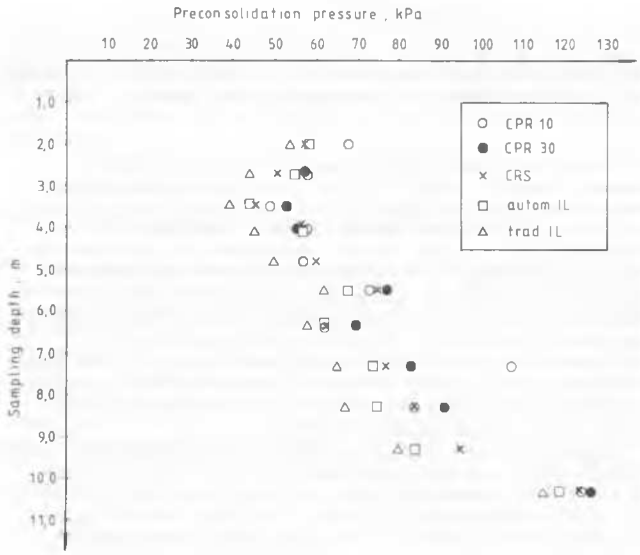

Figure 3. The preconsolidation pressures determined in the comparative oedometer test series.

The figure shows clearly that at each testing level the traditional incremental loading test procedure with 24 hours load increments gives the lowest values of the preconsolidation pressure as was expected. The maximum and minimum differences with various testing procedures compared to these values were:
- in automatic IL test with load application when the excess pore water pressure at the bottom of the sample was 5 % of the previous load increment 3 - 27 per cent
- in CPR test with pore water pressure-load ratio of 10 % (CPR10) 7 - 32 per cent
- in CPR test with pressure ratio of 30 % (CPR30) 10 - 36 per cent
- in CRS test with relative deformation rate of about 0,027 %/min 6 - 28 per cent

The only execption is CPR10 test at depth 7,3 m, which seems to be an obvious test error.

The aforementioned problem with the mathematical determination of the σ_p value in IL tests is illustrated in figure 4. It shows the load-compression curve of the CPR10 test from the depth of 10,3 m (continuous line) and the approximation curve of the automatic IL test at the same level (dotted line). The water content

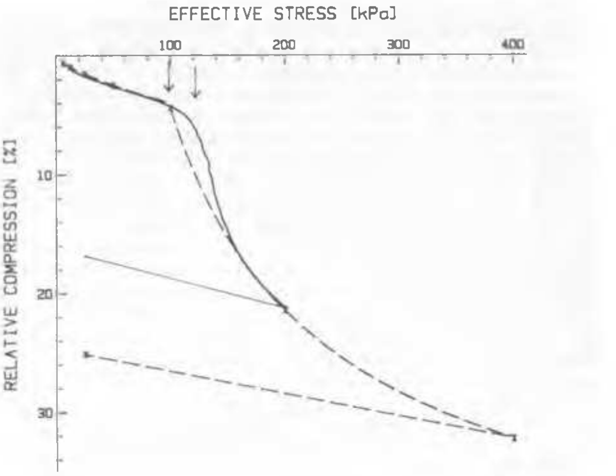

Figure 4. Load-compression curves of the sample no 11 from CPR10 and automatic IL tests.

in both of the samples was 86 %. The figure shows clearly that all of the load-compression points of the automatic IL test fall very close to the continuous curve of the CPR test. However, at stress level from 100 to 160 kPa the curves diverge from each other and therefore also the automatically determined σ_p values differ about 20 %. The simple reason for that is obviously that the IL test just gives no information about the true behaviour of the soil between the stresses of 100 and 200 kPa, and the mathematical approximation oversimplifies the real load-compression curve.

Except the differences between incremental and continuous loading oedometer tests at stresses around the preconsolidation pressure the shape of the compression curves from different types of test corresponded to each other generally well and the differences in compressibility parameters were more due to variations of the water content in individual samples than to the different testing procedures. However, in cases like presented in figure 4 very low values of the parameter β of the Janbus deformation function were obtained in continuous loading oedometer tests. The best overall correlation of the mathematical approximation curve gained with different combinations of the parameters m and β was also usually somewhat better to the points of the IL tests than to the corresponding load-compression curves from the continuous loading test procedures.

5 PERFORMANCE STATISTICS

The test series presented above was performed in summer 1988. Tests were initiated only within the normal working hours, and in that way it took 15 days to perform the 41 automatic oedometer tests of the comparative test series. So the average testing capacity of the new equipment with variable soil materials was more than two and a half tests per day. The work contribution of the laboratorian needed to perform the tests was recorded to be about three to four hours per day.

Of the 41 automatic tests alltogether 38 were consided successful; two CPR tests in the coarsest sample did not give well defined load-compression curves and one CPR10 test seemed to give obviously erroneous results.

The maximum, minimum and average test durations with various test procedures are presented in figure 5. It shows that CPR30 test has been the most rapid type of test, automatic IL test the next and CPR10 and CRS tests the most long lasting test procedures, still possesing an average testing time less than one day.

Simultaneously during the oedometer test series some triaxial tests were also performed, but there is not any statistical data collected from these tests. Anyway the maximum testing capacity would have been 1 - 2 tests per day depending on the shearing rates.

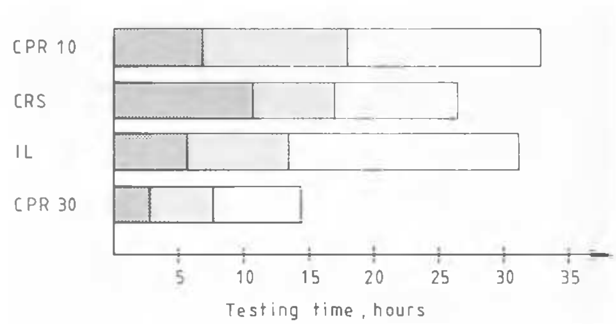

Figure 5. Minimum, average and maximum test durations without unloading in various types of test.

6 CONCLUSIONS

The new triaxial-oedometer device presented in this paper is an encouraging example of the possibilities which the modern micro electronics contributes for the benefit of laboratory equipment development. The new equipment has been functioning harmlessly and it provides versatile testing possibilities with little effort of the laboratory personel. Also the test results have proved to be comparable to the results gained with traditional methods and they are in harmony with the results of earlier investigations.

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