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A Computer-Controlled Triaxial Swelling Test Apparatus

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Abstract

To avoid the problems encountered during and after the construction of engineering structures built within swelling rocks or soils, data related to swelling stresses and strains should be used in the design stage. For an effective design, it is important that the data used for this purpose should be derived from triaxial swelling tests. In this article, a re-designed and computer-controlled triaxial swelling test apparatus is introduced. Due to the limited amount of test equipment, the work associated with triaxial swelling tests has been rather limited and consequently a test standard has not been developed yet. The computer-controlled triaxial swelling test apparatus has made tedious swelling tests easier and thus it has provided better possibilities for the investigation of the triaxial swelling behavior of soils and rocks.

Key words: Swelling, Stress, Strain, Smectite, Confining pressure.

Introduction

Since swelling is a time dependent behavior, obtaining the test results usually takes a long time and thus carrying out these lengthy tests becomes considerably difficult. Therefore the subject requires patient researchers, and, consequently, research associated with swelling phenomena has been rather limited. Any attempt at facilitating execution of the swelling tests will inevitably increase the number of studies on swelling phenomena since it is not possible to shorten the lengthy swelling tests.

As the literature on swelling phenomena is limited there is no standard concerning the swelling test equipment developed yet. Only the International Society for Rock Mechanics (ISRM) Swelling Rocks Commission has made some suggestions about uniaxial swelling test equipment and methods (ISRM, 1989). Other researchers, i.e. Huang *et al.* (1986), Kovari *et al.* (1993), Abduljauwad *et al.* (1998) and Komine and Ogata (1999), studied the development of test equipment and/or methods. The work associated with triaxial swelling test equipment or methods is also rather limited. Franklin (1984), Yeşil (1991), Steiger (1993) and Bilir (2001) are the only researchers have worked on this subject.

Swelling tests are usually carried out under laboratory conditions requiring considerable time and patience. Two basic types of data, i.e. swelling stress and strain data, are gathered from swelling tests. Based on these data, engineering structures are designed in swelling ground. Swelling tests are carried out either under uniaxial or triaxial stresses. In uniaxial swelling tests, since the sample is radially constrained, radial swelling is not permitted, whereas in triaxial test, radial swelling is permitted. Triaxial swelling tests are considered to be much more predominant in reducing uncertainties by simulating in-situ stress state conditions in the laboratory. This may lead to a better definition of swelling ground, and diminishing uncertainties for the complex problems associated with the design work, thus preventing economic and time losses.

In this paper, a modified and re-designed computer-controlled triaxial swelling test apparatus is introduced, and test procedures and the facilitation realized in data recording are explained.

Apparatus

In order to better understand triaxial swelling behavior, Bilir (2001) modified and re-designed the equipment originally developed by Yeşil (1991). The modifications made to the triaxial swelling test equipment are given below:

- Increasing the loading capacity and cell size in order to allow different sample diameters (54, 76 and 100 mm) for uniaxial and triaxial swelling tests,
- Employing a new confining pressure unit to provide constant and continuous pressure.

After these modifications, the triaxial swelling test apparatus was turned into computer-controlled test equipment by the inclusion of a displacement transducer, signal conditioner, data collection card and software for data recording and control. As a result of the modifications, the amount of swelling and load applied to the sample were controlled precisely. Very small variations in such parameters were continuously controlled and recorded, allowing the execution of the test according to its purpose.

The computer-controlled triaxial swelling test apparatus consists of a main frame, confining pressure unit, computer, and software for data collection and control (Figure 1). The main frame consists of a triaxial cell and an axial loading unit (Figure 2).

The triaxial swelling cell includes top and bottom loading platens with porous plates inside, a rubber jacket and seating cylinder, and top and bottom end caps to prevent the leakage of hydraulic fluid (Figure 3). The top and bottom loading platens are cylindrical and made of bronze. There are 6 water holes 8 mm in diameter in each load platen. Furthermore, the outer faces of the loading plates contain some notch type canals to further facilitate water circulation. The porous stones are disk shaped and provide proper water circulation and a smooth loading face for the sample. They are located in both the top and bottom loading platens.

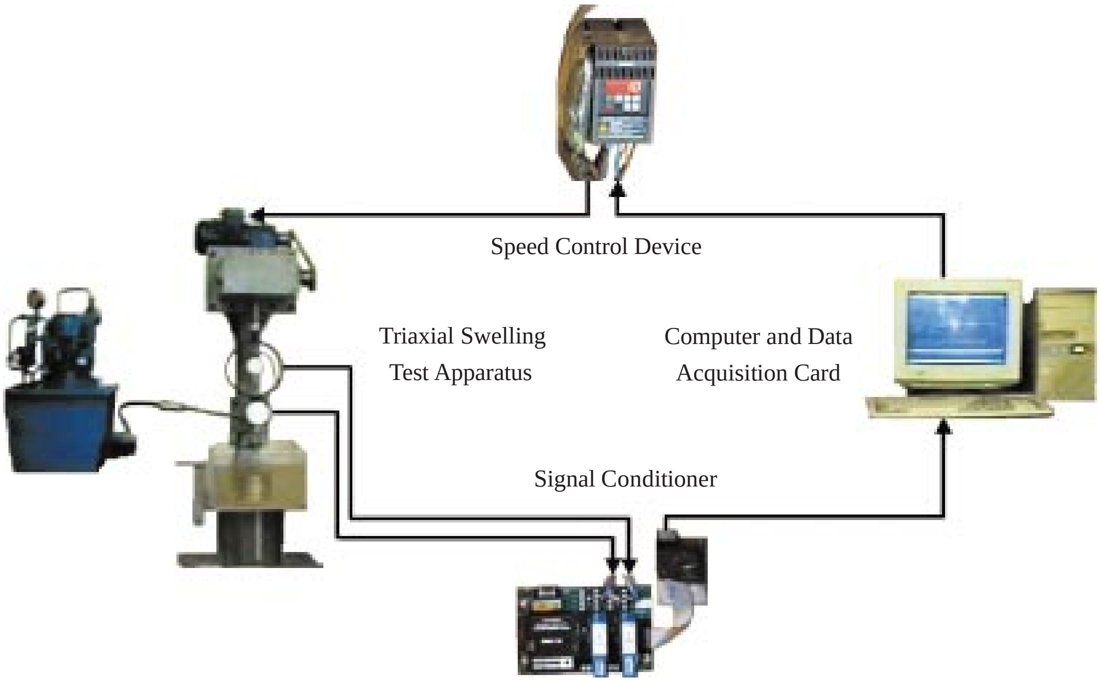


Figure 1. Computer controlled triaxial swelling test apparatus.

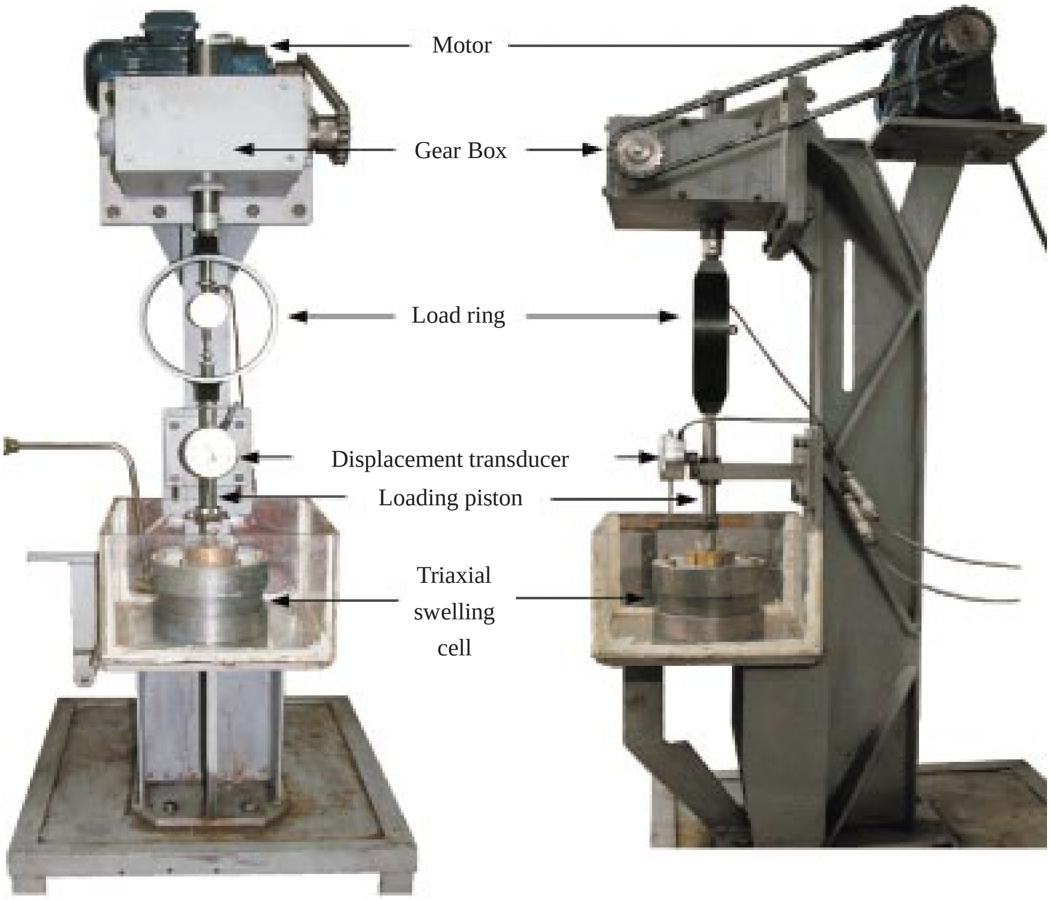


Figure 2. Triaxial swelling test apparatus.

Since the walls are surrounded by bronze, they are not fractured when the confining pressure is applied. The rubber jacket and seating cylinder are used for triaxial tests. The test sample is placed in the rubber jacket, which is placed in the seating cylinder. There is a 1-cm circumferential gap between the wall of the seating cylinder and the rubber jacket for the flow of hydraulic fluid. The hydraulic fluid fills this gap and applies pressure to the specimen. The gap also allows horizontal swelling. The seating cylinder has 6 holes bored in it for bolts to be inserted into. In the case of axial swelling tests, a bronze ring, whose diameter is the same as that of the specimen is used. The upper and lower end caps are both cylindrical and contain a hole large enough for the loading platens to fit into snugly. The end caps exert pressure on the seating cylinder squeezing the flaps of the rubber jacket; in this way, hydraulic fluid leakage is prevented. The upper and lower end caps have 6 holes drilled in them for bolts to fit into. The cell is introduced into a cubic plexiglas container. The container is filled with water to cover the cell completely.

In order to prepare the triaxial cell for experiments, the lower end cap is fixed to the base of the container, into which the lower loading platen is introduced. This is followed by the seating cylinder with the rubber jacket in it (for triaxial swelling tests) or the bronze ring (for axial swelling tests). The upper end cap is attached to the seating cylinder or the bronze ring. The holes in each part are aligned. Six bolts passing through the upper end cap and seating cylinder are fixed to the lower end caps. The specimen is placed on the lower loading platen, and finally the cell assembly is completed by mounting the upper loading platen.

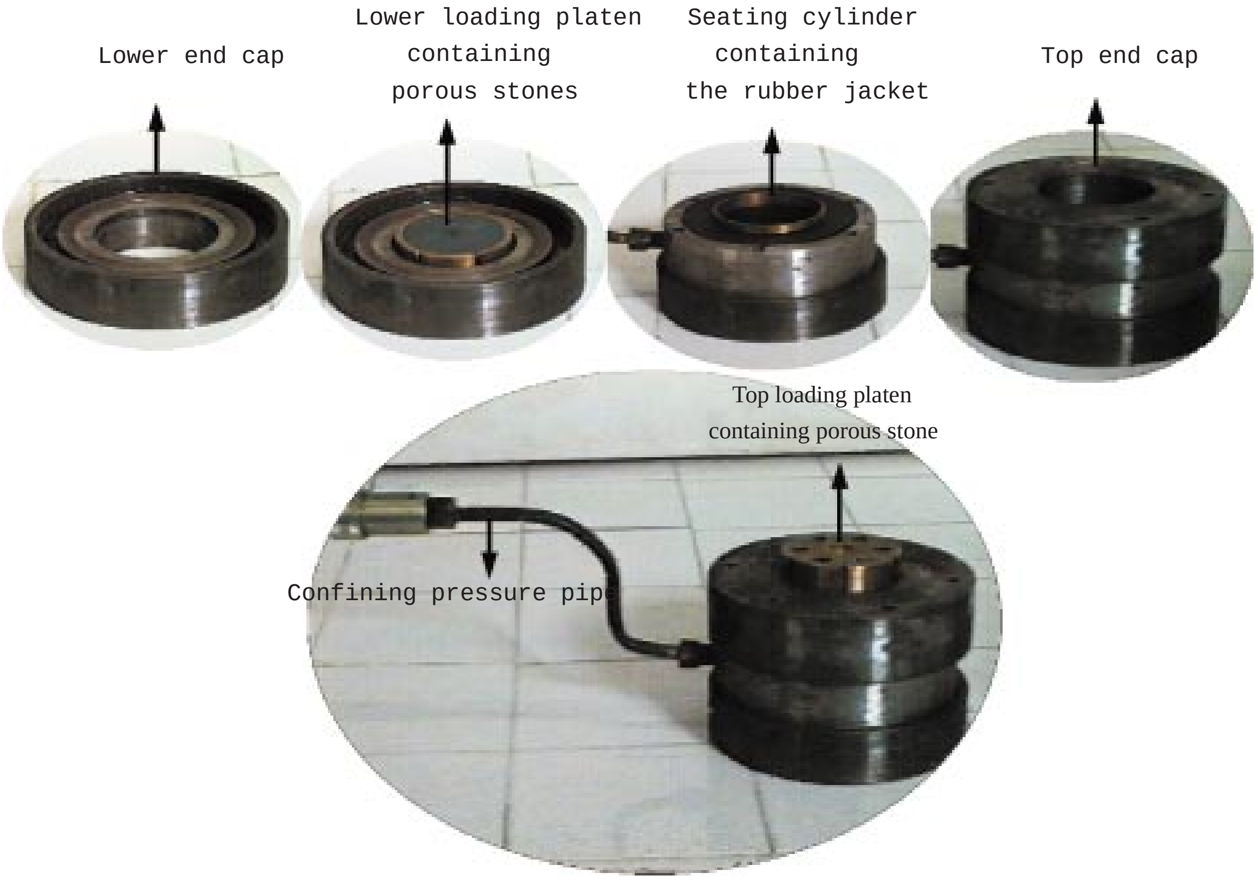


Figure 3. Triaxial swelling cell.

The axial loading unit consists of a displacement transducer, a loading piston, a load ring, a gearbox (reduction gear) and a motor. The loading piston is a cylindrical stainless steel bar. Its lower end is in contact with the upper loading platen and the upper end with the load ring. It transmits the swelling displacements occurring in the specimen to the load ring or the movement of the load ring as a result of the motor operation to the specimen. The displacement transducer has a motion range of 30 mm and a sensitivity of 13.5 μm. It measures displacement in electrical signals. The loading ring has a capacity of 10 kN. It has a displacement transducer with a range of 10 mm mounted in it instead of a mechanical one. Through the calibration curve of the loading ring, any displacement is converted to load and measured as electrical signals with a sensitivity of 0.0216 kN. The motor applies load by producing a forward motion and withdraws it through a backward one. The motion produced by the motor is transmitted to the gearbox by means of a chain, which in turn converts the horizontal motion into vertical motion, thus conveying it to the load ring.

The confining pressure unit consists of an electric motor, a manometer, a spherical valve, a pressure relief valve and a speed control device (Figure 4). The purpose of the confining pressure unit is to apply constant and continuous pressure at any desired level to the specimen by means of hydraulic fluid. For the confining pressure applied to be very gentle, the motor in the unit is operated at very low revolutions. To this end, a speed control device was mounted in the unit, which adjusts the frequency and thus keeps the motor revolution at the desired level.

In the unit in which No. HD 46 oil is used, there are a pair of pressure relief valves, spherical valves and manometers to obtain low and high confining pressures. In order to apply a low confining pressure, the low pressure relief valve is loosened fully and the spherical valve in front of it is turned on.

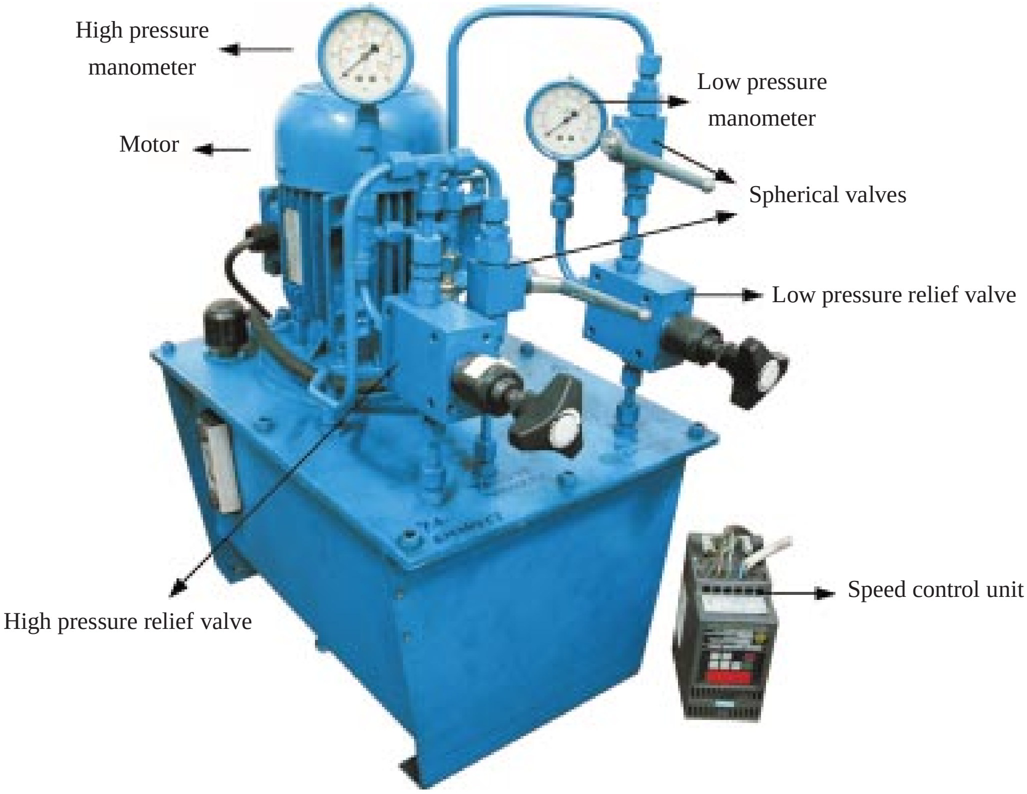


Figure 4. Confining pressure unit.

Then the high pressure valve is tightened and the spherical valve in front of it is turned off. This makes the oil move to the low pressure relief valve. In conjunction with the speed control device, the motor starts to pump oil. The low pressure relief valve is tightened gradually. The tightening process is continued until the manometer indicates the desired level. When the pressure exceeds the adjusted level, the valve is turned on. The oil contributing to excessive pressure is discharged into the oil tank by means of the spherical valve. This process is continued as long as the specimen swells horizontally and the pressure is prevented from exceeding the adjusted level. As the motor constantly pumps oil, the pressure does not fall below the desired level. Accordingly, throughout the experiment, a constant and continuous confining pressure is obtained. By means of the low pressure relief valve with a sensitivity of 0.02 MPa, the applied pressure can be as much as 0.7 MPa.

To obtain a higher pressure, the high pressure relief valve is used. The valve in front of the low pressure relief valve is turned off. This puts the part providing a low confining pressure out of operation. The valve in front of the high pressure relief valve is also turned off. Now the only direction the oil can move in is towards the high pressure relief valve. The motor is operated and the high pressure relief valve is tightened gradually and the desired confining pressure level obtained. The following operational principle is the same as that of the low pressure relief valve. A maximum pressure of up to 4.5 MPa can be applied by means of the high pressure relief valve having a sensitivity of 0.2 MPa.

The computer unit consists of a signal conditioner, a computer, a data acquisition card and a speed control unit. Analog signals released by the displacement transducer during the experiment reach the data acquisition and control card in direct conjunction with the computer after being amplified by the signal conditioner and they are converted into digital ones. The computer program sends these digital signals to the speed control unit, which adjusts the motor revolution. Signals from this unit reach the motor, which produces backward and forward motion. The computer and confining pressure units are connected to a permanent power source. Hence, experiments are not interrupted due to power failure.

Data collection, storage and control processes are performed through a program written in QBasic. The software comprises a Displacement Control Program through which the maximum axial swelling load is determined and a Load Control Program through which the maximum axial displacement is established. The programs involve introducing the hardware and software parameters and their adjustment to zero, checking and applying loads and collecting data. The operational principles are based on the swelling testing methods suggested by ISRM (1989) and the swelling testing methods developed by Yeşil (1991). Three different experiments are carried out using the programs in various ways. The first experiment is one that, by operating the Displacement Control Program once and then the Load Control Program several times, establishes the axial swelling stresses in permitted axial swelling strain under various confining pressure values. In the second the axial swelling stresses are determined under various confining pressure values through the operation of only the Displacement Control Program. The last experiment establishes axial swelling strains under various confining pressures by using only the Load Control Program. The operation of the programs is as follows.

Experimental Phases

The trials, lasting for more than a year, made it possible for the programs to successfully check the performance of the triaxial apparatus. Then tests were carried out, during which the way the specimen dimensions affect triaxial swelling behavior was investigated by means of the triaxial swelling apparatus. To this end, the testing method was employed that establishes axial swelling stress at permitted axial swelling strain under a confining pressure of 0.25 MPa. Here, 3 different graphs are given to show the obtained axial swelling stress and axial swelling strain in relation to the time for 3 specimens of different diameters.

For the bentonite content of the specimen used in the triaxial swelling tests to be controlled, the powdery mixture is pressed. To this end, a special apparatus developed by Yeşil (1991) was used. The specimen preparation apparatus, made of steel, consists of an inner cylinder divided into 4 parts: an external cylinder holding the inner cylinder, an upper cylinder that functions as a guide for the piston, and a piston (Figure 5). In order to prepare a core-shaped specimen, parts of the inner cylinder are introduced into the external cylinder. The upper cylinder is positioned so as to be on top of the inner cylinder. The weighed mixture is poured into the empty space formed and pressed by the hydraulic piston.

When the mark on the piston comes into contact with the upper cylinder, the compression process is stopped. In order to remove the specimen from the assembly, the piston, upper cylinder and external cylinder are disassembled in the correct order. The remaining component is the inner cylinder with the remoulded sample in it. The parts of the inner cylinder can easily be separated from each other and the specimen is obtained.

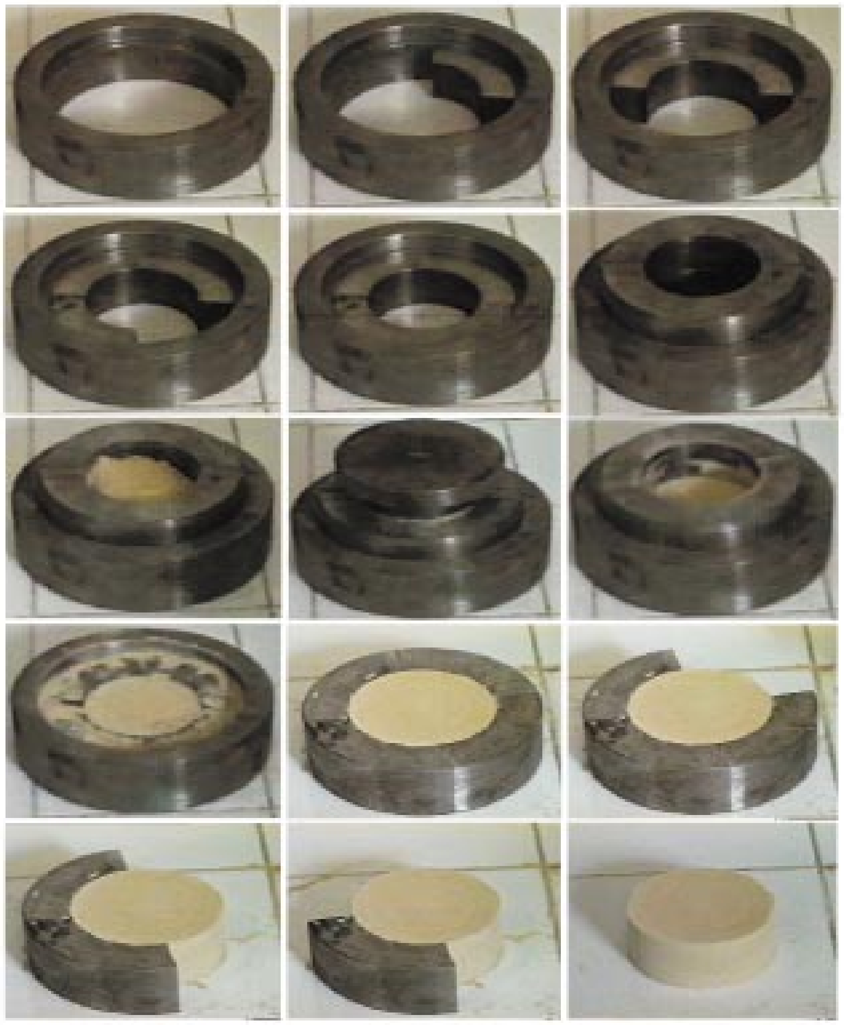
The powdered mixture used in the swelling tests consists of 25% bentonite and fine grained sand (149 –74μm) 75% in weight. The specimen used in the swelling tests had a density of 2 g/cm^3 and diameter/height (D/H) ratio of 2.7 with a diameter of 54, 76 and 100 mm. Mineralogical analysis of the bentonite has revealed 94% clay (all consisting of smectite), 1% quartz, 4% feldspar and 1% calcite.

The thickness and diameter of the specimen are measured at the 3 locations at an angle of 120°. The triaxial swelling cell, which is prepared as described above, is introduced into the water container and centered. The upper loading platen and the loading piston under the load ring are brought into contact with each other. A confining pressure is applied to the specimen. The load and displacement transducers are adjusted to zero. The Displacement Control Program is operated.

The container is filled with distilled water to cover the cell. The water running through the lower and upper loading platens causes the specimen to swell. The program allows a small amount of swelling for the test sample. This swelling value (called the permitted value) is 0.054 mm, which is 4 times the sensitivity of the displacement transducer. As the amount of swelling goes beyond the permitted value of 0.054 mm, the computer sends signals to the motor. The motor runs forward and exerts load on the specimen. When the amount of swelling goes below the permitted value, the computer signals the motor to stop. This cycle repeats itself until the swelling process of the specimen ceases, i.e. the maximum axial swelling load is achieved. The axial swelling load and time are recorded at desired intervals (i.e. every minute). After the maximum axial swelling load is obtained the program stops.

External Cylinder Inner Cylinder Upper Cylinder Piston

a) Parts of sample preparation apparatus.



b) Application phases.

Figure 5. Parts of sample preparation apparatus (a) application phases (b).

The value obtained as described above is entered into the Load Control Program and the program is operated. If the Load Control Program is operated solely for determining the maximum swelling displacement, the maximum swelling load entered is zero. The program, on the basis of this value, calculates to what level the load will be reduced. In general, the reduced load level applied as half the previous axial swelling load is the limit value at which load control is performed. In line with the signal from the computer, it causes the motor to reverse and remove the load from the specimen until the limit load level is achieved. Thus the specimen begins to swell and the swelling causes the load to exceed the limit value. The program restarts the motor and lowers the load below this limit value. The cycle repeats itself until the specimen stops swelling. The axial swelling displacement and time are recorded at desired intervals. The program stops until it yields the maximum axial swelling displacement at the reduced load level. By operating the Load Control Program a few more times, maximum axial swelling displacements corresponding to various reduced load levels are established. The axial swelling load (N) and axial swelling displacement values (h) obtained from the programs are put in their respective places in the following equations and the axial swelling stress (σ_s) and axial swelling strain (ε_s) are calculated.

$$\sigma_s = N/A \qquad (1)$$

$$\varepsilon_s = h/H \qquad (2)$$

Analysis of the Swelling Data

The axial swelling stress and axial swelling strain in relation to time for the specimens of diameter 54, 76 and 100 mm are shown in Figures 6 to 11, respectively. These figures indicate that the axial swelling stress and axial swelling strain require 2.5–5 and 10–40 days, respectively, to reach their maximum values. In the experiments, when the axial swelling strains are established, the less the load on the specimen becomes, the more time the displacement requires to reach its maximum value. In comparison with the axial swelling strain, the axial swelling stress can be determined in a shorter period of time. Data continuously recorded during the swelling test are evaluated by the program, which enables one to check if the permitted values are exceeded or not. Accordingly, the motor applies or removes the load on the specimen. Furthermore, readings for axial swelling stress, axial swelling strain and time are taken every 3 min. In this way, the swelling tests are carried out by the computer in a sensitive manner and any small change in the trend in the swelling curve can be easily monitored. For example, about 1200 items of data can be collected during 2.5 days of experiment. The results of the experiments carried out by Tabrizian (1989) and Özçelik (1995) by means of a triaxial swelling apparatus developed by Yeşil (1991) are given in Figures 12a and b. The graphs indicating swelling stress and swelling strain in relation to time were plotted by employing a small amount of data. Kaya (1997) reports that the periodical readings during the experiments can only be taken during the working hours. Only 15 swelling values could be collected from over 3 days of experiment (Figure 12c).

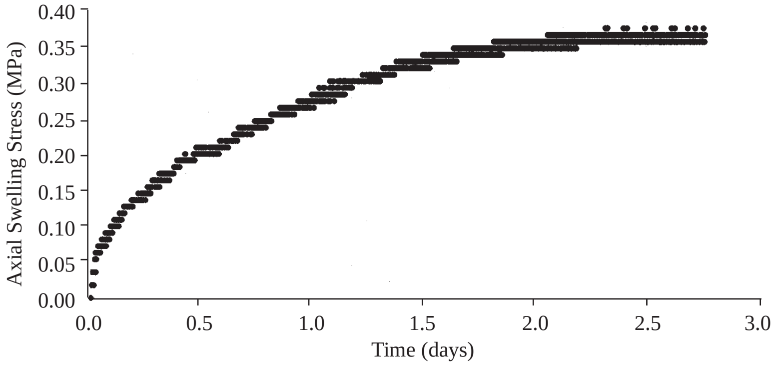


Figure 6. Variation of axial swelling stress with time for 54 mm diameter sample at 0.25 MPa confining pressure with constant volume.

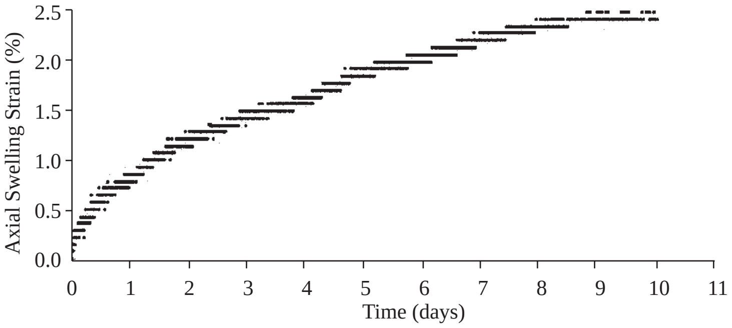


Figure 7. Variation of axial swelling strain with time for 54 mm diameter sample under 0.256 MPa axial stress at 0.25 MPa confining pressure.

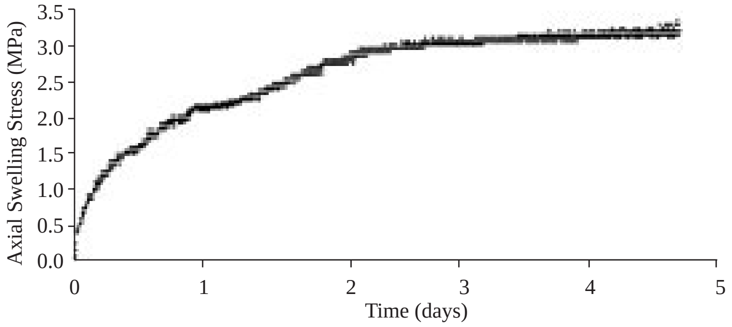


Figure 8. Variation of axial swelling stress with time for 76 mm diameter sample at 0.25 MPa confining pressure with constant volume.

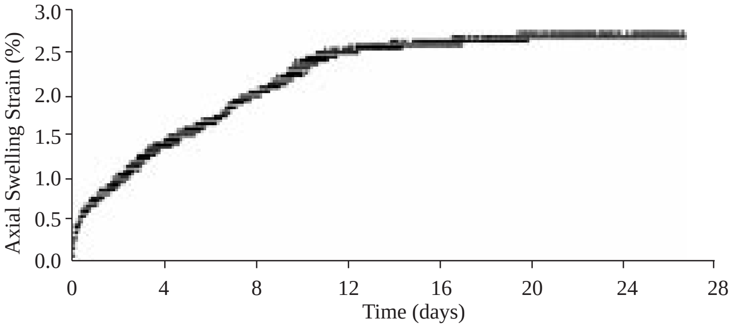


Figure 9. Variation of axial swelling strain with time for 76 mm diameter sample under 0.210 MPa axial stress at 0.25 MPa confining pressure.

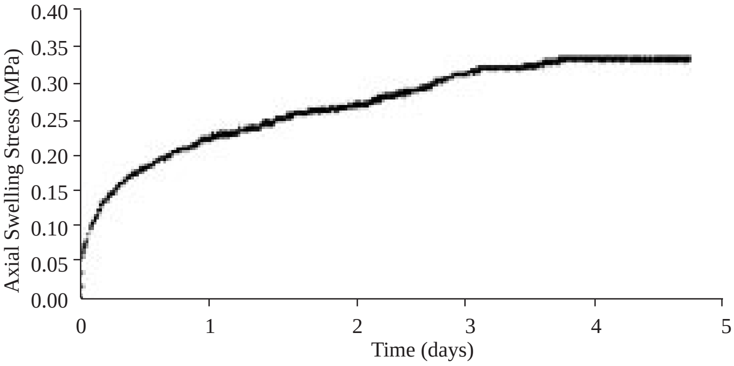


Figure 10. Variation of axial swelling stress with time for 100 mm diameter sample at 0.25 MPa confining pressure with constant volume.

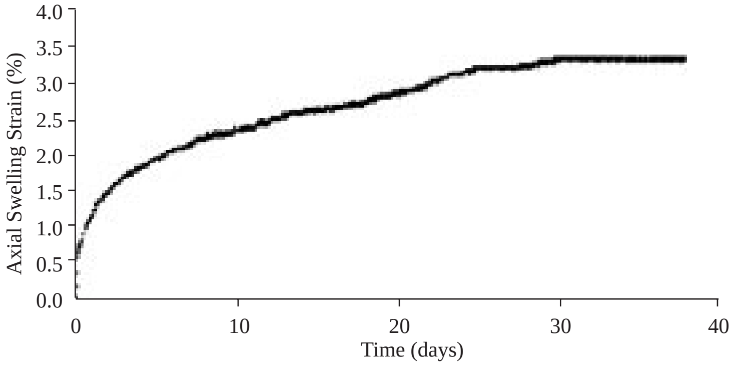


Figure 11. Variation of axial swelling strain with time for 100 mm diameter sample under 0.183 MPa axial stress at 0.25 MPa confining pressure.

Conclusion

The swelling equipments and methods suggested by ISRM (1989) are those based on axial swelling tests. As there has been little research into triaxial swelling behavior, no standards have been established yet. For triaxial swelling behavior that reflects actual stress to be investigated in a more realistic manner, the first requirement is an apparatus to carry out the experiment. The design of the triaxial swelling apparatus and its connection to a computer for control have not only made research into triaxial swelling behavior possible but also led to advantages that facilitate experiments:

- Performing a sensitive experiment and controlling changes according to the purpose of the test.
- Opportunity for obtaining data frequently owing to the ability to adjust the periods of data recording.
- Eliminating the need for human labor by controlling and recording data by means of a computer during the swelling experiments lasting from a few days to a few months.
- Conducting swelling experiments on specimens of various diameters.

The results of this research in which the effects of the specimen dimensions on the swelling parameters were investigated will constitute the subject of our next publication. The computer-controlled triaxial swelling apparatus introduced here is one of the few mentioned in the literature. Use of this apparatus in the future will help to solve the swelling problems encountered in mining, civil, geological and petroleum engineering.

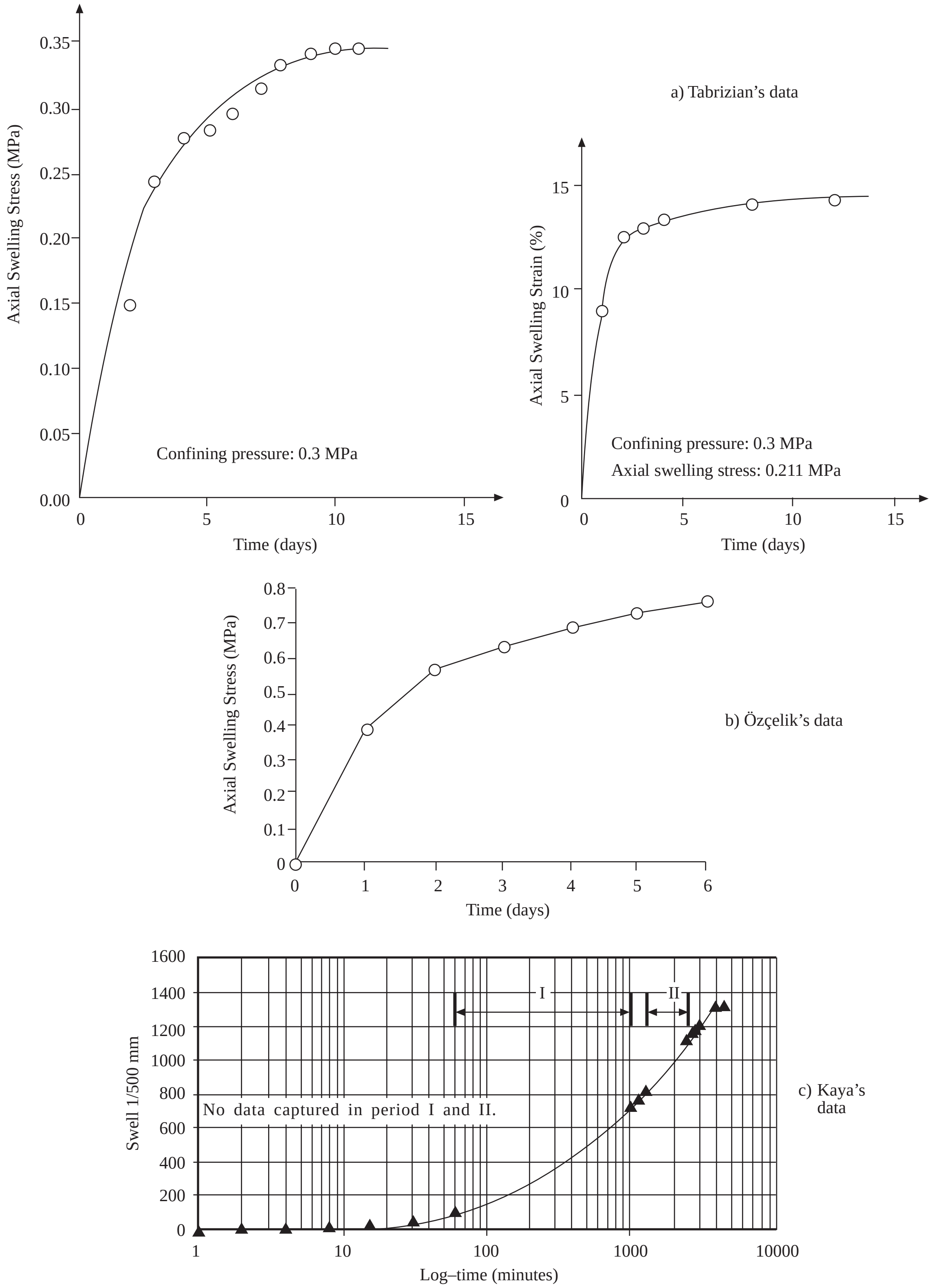


Figure 12. Variation of swelling data with time gathered by Tabrizian (1989), Özçelik (1995) and Kaya (1997).

Nomenclature

A	cross sectional area of specimen
h	measured axial swelling displacement
H	initial thickness of the specimen
N	measured axial swelling load
ε_s	axial swelling strain
σ_s	axial swelling stress

Acknowledgments

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