

**THERMO-HYDRO-MECHANICAL
CHARACTERIZATION
OF THE SPANISH REFERENCE
CLAY MATERIAL
FOR ENGINEERED BARRIER
FOR GRANITE AND CLAY
HLW REPOSITORY: LABORATORY
AND SMALL MOCK UP TESTING**

**THERMO-HYDRO-MECHANICAL
CHARACTERIZATION
OF THE SPANISH REFERENCE
CLAY MATERIAL
FOR ENGINEERED BARRIER
FOR GRANITE AND CLAY
HLW REPOSITORY: LABORATORY
AND SMALL MOCK UP TESTING**

M.V. Villar

Collaborates: J. Cuevas, P.L. Martín, R. Campos & A.M. Fernández

*CIEMAT
DIRECCION DE TECNOLOGIA
TECNICAS GEOLOGICAS*



**THERMO-HYDRO-MECHANICAL
CHARACTERIZATION
OF THE SPANISH REFERENCE
CLAY MATERIAL
FOR ENGINEERED BARRIER
FOR GRANITE AND CLAY
HLW REPOSITORY: LABORATORY
AND SMALL MOCK UP TESTING**

*This report has been drawn up on behalf of ENRESA.
It represents the opinion of the contractor which need not necessarily
coincide with that of ENRESA in every respect.*

INDEX

RESUMEN.....	1
1. INTRODUCTION	7
2. DESCRIPTION OF THE STUDIED CLAY	11
3. EXPERIMENTS PERFORMED	15
3.1. Tests on high density compacted clay blocks.	17
3.1.1. Thermohydraulic cell	17
Description of the cell and experiments	17
Results	18
– Temperature distributions.	18
– Hydration process.	18
– Final water content and density distributions	19
– Solute movement	19
Conclusions	20
3.1.2. Alteration cell	21
Description of the cell and experiments	21
Results.	21
Discussion	21
3.2. Suction controlled tests.	21
– Air pressure method	22
– Sulfuric acid solutions method	22
3.2.1. “Water content vs suction” curve.	22
Experimental technique.	22
Results.	22
3.2.2. Suction controlled oedometer tests	23
Experimental technique.	23
Results and Discussion	24
3.3. Triaxial tests	25
Experimental technique.	25
Results.	25
3.4. Thermal conductivity	26
3.5. Influence of temperature on hydraulic conductivity.	26
3.6. Interstitial water	26

4. REFERENCE	27
5. TABLES	31
6. FIGURES	37
ANNEX I	55
ANNEX II	113
ANNEX III	127
ANNEX IV	139

RESUMEN

CARACTERIZACION TERMO-HIDRO-MECANICA DE ARCILLAS ESPAÑOLAS COMO MATERIAL DE REFERENCIA EN LAS BARRERAS DE INGENIERIA PARA ALMACENAMIENTO GEOLOGICO PROFUNDO EN FORMACIONES EN GRANITO Y ARCILLA: ENSAYOS EN LABORATORIO Y MAQUETA

Este trabajo presenta los resultados obtenidos por la División de Técnicas Geológicas del CIEMAT dentro del marco del Contrato CEC FI2W-CT91-0102(DOEO), coordinado por SCK-CEN (Bélgica) en el que participan además la UPC-DIT y la Universidad de Gales. El papel de CIEMAT en el proyecto ha consistido en la realización de ensayos de laboratorio en los que se simulan las condiciones de la barrera arcillosa en el almacenamiento, con el doble objeto de identificar procesos y determinar parámetros, lo que ha servido de calibración y validación para los equipos de modelización participantes en el proyecto (UPC-Barcelona, UWCC-Cardiff). Los resultados del proyecto completo serán publicados por la UE en la serie EUR.

Los ensayos se han centrado fundamentalmente en dos aspectos: por una parte en la reproducción de la interacción del calor proveniente de los residuos y del agua procedente del medio geológico circundante sobre bloques de arcilla compactada, y por otra, en el estudio del comportamiento mecánico de la arcilla en condiciones subsaturadas. Se ha trabajado con una de las arcillas candidatas españolas, la montmorillonita de referencia S-2 proveniente de Serrata de Níjar (Almería), cuya caracterización previa y detallada se puede encontrar en Rivas et al. (1991).

Para la simulación de la interacción de los flujos térmico e hidráulico sobre bloques de arcilla de alta densidad, se han construido dos celdas cilíndricas de acero inoxidable: la celda termohidráulica y la celda de alteración. La primera de ellas aloja un bloque de arcilla de 15 cm de diámetro y 14.6 cm de altura (Fig. 1). Permite la hidratación uniforme de la arcilla mediante inyección de agua por la base de la celda, y su calentamiento en la parte superior central a través de dos calentadores intercambiables: uno de 1 cm de longitud y otro de 10 cm de longitud. La evolución de temperatura en la arcilla se sigue mediante termopares colocados en diferentes posiciones. La segunda

celda, de dimensiones inferiores, 3.8 cm de diámetro y 7.8 cm de altura (Fig. 4), recibe el calentamiento por toda la superficie de su base, y la hidratación por la parte superior, de manera que ambos frentes son aproximadamente paralelos (Fig. 5). Los experimentos realizados en estas celdas han permitido un mejor conocimiento de la fuente de calor, el sistema de hidratación y los sensores, y han aportado interesantes datos sobre la difusión de agua y calor y sobre las transformaciones físico-químicas ocurridas en la arcilla.

Los experimentos se han realizado sobre montmorillonita compactada a densidad seca 1.65 g/cm^3 con diferentes humedades iniciales. Después de períodos variables de calentamiento y/o hidratación el bloque es extraído de la celda y seccionado para obtener muestras representativas de diferentes niveles. Sobre las muestras así obtenidas se realizan determinaciones de humedad, densidad, superficie específica, distribución del tamaño de poros y, en extractos acuosos de la muestra, se determina la conductividad eléctrica, concentración de cloruros, sulfatos y sílice (Anejos I y II).

Las principales conclusiones extraídas de estos experimentos son:

- La distribución de temperaturas en los bloques de arcilla está condicionada por la geometría y potencia del calentador, así como por las conductividades térmicas de los materiales que los rodean, pareciendo ser independiente de la humedad de la arcilla, al menos en el rango de humedades estudiado (10-20%).
- Para los períodos de tiempo considerados (hasta 2500 horas), la cinética de hidratación no se ve afectada por el gradiente térmico, sino por la humedad inicial de la arcilla, es decir por su succión o avidéz por el agua, que hace que cuánto menor sea la humedad inicial de la arcilla más rápido sea el proceso de hidratación.

- La distribución final de humedades está condicionada por el gradiente térmico. La entrada de agua produce un aumento de humedad que se traduce en un hinchamiento y consiguiente descenso de densidad de la arcilla hidratada. Esta expansión de la arcilla más hidratada produce un aumento de densidad en las áreas adyacentes no afectadas todavía por el proceso de hidratación, ya que todo el proceso se realiza a volumen constante.
- No se han observado concentraciones importantes y/o preferenciales de sílice libre en ningún experimento, por lo que se supone que no se han producido cementaciones.
- Hacia las zonas calientes se produce una concentración de sales que previamente son lavadas de las zonas atravesadas por el frente de hidratación. Se trata fundamentalmente de cloruros y sulfatos, y se ha observado un comportamiento diferente en ambos. Los cloruros muestran una mayor movilidad y son fácilmente transportados por convección hacia las zonas calientes desde el principio de la hidratación. Una vez que el bloque está saturado se difunden también con facilidad obedeciendo a gradientes de concentración, homogeneizándose su concentración en todo el bloque. La movilidad de los sulfatos es más limitada, siendo su cinética mucho más lenta. Esta concentración salina cerca del calentador puede llegar a ser muy importante durante la fase de saturación de la barrera, por lo que podría afectar a la corrosión del contenedor.
- La superficie específica externa (BET) de la arcilla disminuye hacia las zonas más calientes, así como la proporción de poros pequeños registrada en las porosimetrías, lo que puede atribuirse a la agregación de cristales de montmorillonita por efecto del calor.

Los bloques de arcilla se dispondrán en la barrera con la humedad correspondiente a su estabilización en condiciones ambientales normales (15%), es decir, con un grado de saturación inferior al 50%. Debido al calor emitido por los residuos, así como a la baja permeabilidad de la barrera y a la limitación de agua disponible en el medio geológico, la arcilla permanecerá subsaturada durante un período de tiempo importante.

De ahí surge la necesidad de llegar a un mayor conocimiento del comportamiento de la arcilla en estado subsaturado. Para ello se han realizado varios tipos de ensayos bajo succión controlada: determina-

ción de la relación succión-humedad, ensayos edométricos y ensayos triaxiales.

La gran expansividad de la montmorillonita S-2 así como su elevada succión para las humedades a las que normalmente se trabaja, han hecho necesario el desarrollo de técnicas y equipos especiales, debido fundamentalmente a que no existe instrumentación que permita medir succiones tan elevadas en materiales expansivos, y por lo tanto, para controlar la succión a la que se trabaja es necesario imponerla. Para ello se han utilizado dos métodos: el conocido como "traslación de ejes", que consiste en la aplicación de una presión de nitrógeno (Fig. 9), y la imposición de una humedad relativa determinada mediante disoluciones de ácido sulfúrico de diferente densidad (Fig. 10).

El paso previo para cualquier estudio sobre el comportamiento de la arcilla subsaturada es la determinación de la curva que relaciona la succión impuesta con la humedad alcanzada por la arcilla. Se ha comprobado que existe una relación logarítmica entre la humedad de equilibrio y la succión, y que esta relación es independiente de la densidad y humedad inicial de la arcilla. A 20 °C y con su humedad de estabilización (11%) la montmorillonita tiene una succión de 133 MPa (Fig. 12).

Los ensayos edométricos se han realizado sobre montmorillonita compactada con su humedad natural a una densidad de 1.60 g/cm³. Se la ha sometido a ciclos de secado-humectación-carga-descarga y de humectación-secado-carga-descarga, con el fin de observar la influencia en su comportamiento (endurecimiento, reversibilidad, colapso) tanto de la succión impuesta como de la carga vertical a que se ve sometida. La determinación final de distribución de tamaño de poros permite conocer el nivel estructural (micro o macro) más afectado por estos procesos.

Los ensayos triaxiales se han realizado en equipos convencionales sobre muestras de diferentes humedades que se mantienen constantes durante todo el ensayo, pero sin que exista un control de la succión. Estos ensayos permiten determinar los parámetros de rotura de la arcilla, cohesión y ángulo de rozamiento. Ambos parámetros aumentan al disminuir el grado de saturación de la arcilla, puesto que ésta sufre un "endurecimiento" debido al aumento de fuerzas capilares y se hace más resistente (Fig. 17).

Como complemento a los estudios expuestos hasta aquí, se ha realizado una revisión de los datos de permeabilidad a diferentes temperaturas obtenidos en ensayos previos (Fig. 20) y de los de conductividad térmica para diferentes densidades y humedades (Fig. 19), ajustándose una curva que relaciona conductividad térmica con el grado de saturación.

Finalmente, se ha realizado un estudio bibliográfico sobre los métodos de extracción del agua intersticial de la arcilla. Como método de obtención del agua más representativa de la que está en equilibrio

con la arcilla se ha elegido la extracción por compactación a altas presiones, diseñándose y construyéndose un “estrujador” que permite la compactación de la muestra hasta presiones de 100 MPa (Fig. 21).

1

INTRODUCTION

1

INTRODUCTION

This Report refers to the work carried out by División de Técnicas Geológicas of CIEMAT (CIEMAT.DT.TG) coordinated by SCK/CEN (Belgium), participating besides UPC-DIT and University of Wales on the framework of CEC Contract FI2W-CT91-0102 (DOEO). It presents the results obtained. The total results on the project will be published by CEC in the EUR series.

The role of CIEMAT in this project was to carry out tests in which the conditions of the clay barrier in the repository were simulated. The interaction of heat coming from the wastes and of water coming from the geological medium has been reproduced on compacted clay blocks. For the performance of tests on high density compacted clay blocks (Task 2.1) and for the cementation and chemical-mineralogical transformation studies, two different cells were designed and constructed in stainless steel: a thermohydraulic cell and an alteration cell. The experiments performed in these cells have provided us with a better knowledge of the heat source, hydration system and sensors, as well as interesting data on heat and water diffusion. A revision of the experiments performed on the thermohydraulic cell was presented at the "International Workshop on Thermomechanics of Clays and Clay Barriers" held in Bergamo in October '93 (Villar et al. 1993).

The clay in the barrier is supposed to remain unsaturated during a certain period of time, due to its low permeability and to the heat source of the canister. For this reason, some tests have been

performed in order to achieve a better knowledge of the unsaturated behaviour of the clay.

Besides the determination of the "water content vs suction curve", that gives the relationship between the water content in the clay and its suction, oedometer and triaxial tests have been performed in the unsaturated montmorillonite. The first results of the suction-controlled oedometer test were presented at the Conference "The Engineering Geology of Waste Storage and Disposal" held in Cardiff in September '93 (Villar & Martín 1993). There has been a significant advance on the development of experimental techniques and good innovative results have been obtained.

Permeability data from experiments at different temperatures performed three years ago have been revised and are now available. New determinations of thermal conductivity of montmorillonite have been done.

We have done a bibliographic research on the methods normally considered for the extraction of interstitial water in clays. All these techniques have been tested, and a "squeezing device", that will allow the compaction of the sample to 100 MPa, has been constructed.

Most of the results obtained on account of this Project will be useful for the partners of CEC Contract FI2-CT91-0033 (DOEO), in which we participate as observers.

performed in order to achieve a better knowledge of the unsaturated behaviour of the clay.

Besides the determination of the "water content vs suction curve", that gives the relationship between the water content in the clay and its suction, oedometer and triaxial tests have been performed in the unsaturated montmorillonite. The first results of the suction controlled oedometer test were presented at the Conference "The Engineering Geology of Water Storage and Disposal" held in Cardiff in September '93 (Villar & Martin 1993). There has been a significant advance on the development of experimental techniques and good innovative results have been obtained.

Intermixing data from experiments at different temperatures performed three years ago have been revised and are now available. New determinations of thermal conductivity of montmorillonite have been done.

We have done a bibliographic research on the methods normally considered for the extraction of interstitial water in clays. All these techniques have been tested and a "squeezing device", that will allow the compaction of the sample to 100 MPa, has been constructed.

Most of the results obtained on account of this Project will be useful for the partners of CEC Contact P12 CT91 0033 (DOBO), in which we participate as observers.

This Report refers to the work carried out by Division de Technos Géologiques of CEMAT (CEMAT-DT) coordinated by SECKAËN (Belgium), participating besides UPC-DIT and University of Wales on the framework of CEC Contract P12W-CT91-0103 (DOBO). It presents the results obtained. The final results on the project will be published by CEC in the BLUE series.

The role of CEMAT in this project was to carry out tests in which the variation of the clay content in the specimens was controlled. The parameters of heat transfer from the water and of water content in the specimens were monitored. For the performance of tests on high density compacted clay blocks (T₀ = 1.1) and for the construction and chemical-thermodynamic characterisation of two different cells were designed and constructed in stainless steel. The thermodynamic cell and an extraction cell. The experiments performed in these cells have provided us with a better knowledge of the heat source, hydration system and sensors, as well as interesting data on heat and water diffusion. A revision of the experiments performed on the thermodynamic cell was presented at the "International Workshop on Thermodynamics of Clays and Clay Minerals" held in Bergamo in October '93 (Villar et al. 1993).

The clay in the barrel is supposed to remain unsaturated during a certain period of time, due to its low permeability and to the heat source of the heater. For this reason, some tests have been

2

DESCRIPTION OF THE STUDIED CLAY

DESCRIPTION OF THE STUDIED CLAY

2

The tests have been performed on a Spanish montmorillonite from Almería (reference S-2), that was chosen after a selection process among other Spanish bentonites. After receiving it from the quarries, it has been dessicated at 60 °C during 48 hours and then ground to a size less than 2 mm. It has been stabilised at laboratory conditions, i.e., 20-25 °C and 60% relative humidity, for its use in the laboratory experiments. It contains low quantities of biotite, plagioclase and quartz (less than 5%), fragments of volcanic rocks and probably colloidal silica. It was originated by the hydrothermal alteration of volcanic rocks. Its main physico-chemical characteristics (Rivas et al. 1991 and Pérez del Villar et al. 1991), are shown below:

- Specific surface (internal+external): 570 m²/g
- External specific surface (BET): 37 m²/g
- Liquid limit: 213%
- C.E.C.: 88 meq/100 g
- Exchangeable cations: Ca²⁺: 42 meq/100g
Mg²⁺: 26 meq/100g

Na⁺: 18 meq/100g
K⁺: 2 meq/100g

- Water content at laboratory conditions: 10-13% (by oven-drying)
- Specific weight: 2.78

The specific weight has been determined using classical picnometers and bidistilled water as suspension medium.

Some relationships between dry density (ρ_d , g/cm³) and saturated hydraulic conductivity (K, m/s) and between dry density and swelling pressure (Ps, MPa) can be found in Villar & Rivas 1994:

- For ρ_d between 1.4 and 2.0 g/cm³:
 $\log K = -2.2 \rho_d - 9.1$
- For ρ_d between 1.1 and 1.4 g/cm³:
 $\log K = -6.3 \rho_d - 2.9$
- For ρ_d in the range from 1.3 to 2.0 g/cm³:
 $\ln P_s = 5.9 \rho_d - 7.9$

The tests have been performed on a Spanish montmorillonite from Alameda (reference 8-2), that was chosen after a selection process among other Spanish bentonites. After receiving it from the producer, it has been heated at 60 °C during 48 hours and then ground to a size less than 2 mm. It has been analysed at laboratory conditions, i.e., 20-25 °C and 60% relative humidity, for its use in the laboratory experiments. It contains low quantities of organic pigments and quartz (less than 1%). Experiments on swelling, toxicity and permeability indicated that it was not affected by the hydrocarbon. Absorption of organic matter by the bentonite (chemical characterisation given in de Vries and Pijpers 1991) is shown below:

- * Specific surface (internal+external): 270 m²/g
- * External specific surface (BET): 37 m²/g
- * Liquid limit: 113%
- * CEC: 88 meq/100g
- * Exchangeable cations: Ca²⁺: 42 meq/100g
Mg²⁺: 26 meq/100g

- * Water content at laboratory conditions: 10-13% (by oven-drying)
- * Specific weight: 2.78
- * Na⁺: 18 meq/100g
K⁺: 2 meq/100g

The specific weight has been determined using classical pycnometers and bidistilled water as suspension medium.

Some relationships between dry density (ρ_d, g/cm³) and estimated hydraulic conductivity (K, m/s) and between dry density and swelling pressure (P_s, MPa) can be found in Vitor & Rivero 1994:

- * For ρ_d between 1.4 and 1.6 g/cm³:
log K = -2.2 ρ_d - 9.1
- * For ρ_d between 1.1 and 1.4 g/cm³:
log K = -6.3 ρ_d - 2.9
- * For ρ_d in the range from 1.3 to 2.0 g/cm³:
in P_s = 5.9 ρ_d - 7.9

3

EXPERIMENTS PERFORMED

3

EXPERIMENTS PERFORMED

3.1 Tests on high density compacted clay blocks.

The diffusion of water and vapour in the clay and the cementation processes and chemical-mineralogical transformations are closely related, as the latter are the result of the diffusion of heat and water in liquid or vapour state.

Two kinds of cells, in which a compacted sample of clay is simultaneously heated and hydrated by opposite fronts, were constructed. These are the thermohydraulic cell and the alteration cell. In both cases the experiments have been performed with montmorillonite uniaxially compacted to a dry density of 1.65 g/cm^3 .

3.1.1. Thermohydraulic cell

Description of the cell and experiments

A stainless steel cell has been designed and constructed. A comprehensive sketch with its components is shown in Fig. 1. It has an inner diameter of 15 cm, a height of 14.6 cm and a wall thickness of 3.6 cm. The bottom of the cell is provided with two hydration ports leading to the porous plate. In the upper part, the heating device is placed along the axis of the cylinder. It consists of a resistance electronically regulated by an ON/OFF temperature controller with a thermocouple sensor. Two different heater configurations have been used. In the first the heater element is 1.5 cm long and 1 cm diameter (Fig. 1a). In the second, which produces an axial heating, the element is 10 cm long and 2 cm diameter (Fig. 1b). To attain a constant heating temperature of 100°C , the instantaneous power in the small heater has been fixed to 37 W and in the axial one to 40 W.

The cell wall has nine ports at three different levels for the introduction of the thermocouples at three different radio. Chromel-alumel thermocouples with stainless steel sheaths of 0.1 cm diameter have been used. The clay temperature measured by the nine thermocouples is logged by a Data Acquisition System. This allows to determine the temperature distribution in the clay at different times. The cell has three additional holes at the same levels to accommodate the swelling pressure transducers.

The material used in all the experiments has been Spanish montmorillonite. The clay was uniaxially compacted inside the cell to a dry density of around 1.65 g/cm^3 . In some experiments water was added in order to have an initial water content of 15 and 20%,

besides the stabilization one. Either the 1 cm long or the axial heater has been used. The temperature in the heating device has been set to 100°C . In Ex3 to Ex7 the samples were submitted to heating-cooling cycles for different periods of time. Hydration was achieved in four experiments by injecting distilled or running water with a pressure of 1 MPa through the lower ports, using an automatic pump. The volume of water inflow was measured by an automatic volume change apparatus of 0.001 cm^3 accuracy. In some experiments, the cell was covered by a warm water shower at 30°C , in order to reduce the effects of room temperature variations ($17\text{--}25^\circ\text{C}$). A summarized description of the experiments is given in Tables I and II.

At the end of the experiments the samples were taken out and sliced. The slices were analysed by measuring the final water content and dry density. Water content (w) is defined here as the ratio between the weight of water lost after heating the sample to 105°C for 24 hours and the weight of the dried clay, expressed as a percentage. The volume used to calculate the dry density (pd) was measured by mercury displacement.

For the long period hydration experiments Ex6 and Ex9, additional parameters have been determined in subsamples similar to those taken for the humidity and density measurements. These are: the electrical conductivity, chlorides and sulfates in a 1+5 aqueous extract, the free extractable SiO_2 in a 0.1M Na_2CO_3 solution, specific surface and pore size distribution. These parameters have been selected to test some of the main chemical factors that can modify the mechanical behaviour of the compacted bentonite, i.e., cementation and salt concentration.

The electrical conductivity (EC) and chloride and sulfate concentrations have been measured in a distilled water extract. A mass of 2.5 g of air dried clay was dispersed in 10 cm^3 of distilled water by stirring for 48 hours. The suspension was centrifuged and the EC was measured with an electrometric cell. The concentration of anions in this extract was determined by ion chromatography.

To determine the amount of siliceous cement (free silica) a selective alkali dissolution method was used (modified from Smith and Mitchell 1987). 2.5 g of clay were dispersed in 40 ml 0.1M Na_2CO_3 , and the resulting suspension was placed in 50 ml polyethylene centrifuge tubes and stirred for 48 hours at room temperature. The suspension was then centrifuged and silica was measured by the silico-molibdic colorimetric method. Silica is reported as ppm by weight of the air dried clay.

Specific surface values are referred to external surface, as they are measured using the BET method, in which the adsorbing gas, nitrogen, does not occupy the interlamellar space. A Flowsorb II 2300 apparatus of Micromeritics has been used. The specific surface values can suggest a modification of the microscopic structure of the clay.

Pore size distribution is measured by mercury porosimetry using a Poresizer 9310 of Micromeritics, with a pressure range for the injection of mercury from 7 kPa to 210 MPa, which allows to measure pore diameters from 100 μm to 0.003 μm . It must be pointed out that mercury does not intrude in fact the interlamellar space (around 20 $\text{\AA}$). Prior to the testing the samples must be dried. Although in some cases the samples were oven-drying, freeze-drying has been the chosen technique.

It involves plunging a specimen into a cryogenic liquid at its melting point (liquid nitrogen, -196 $^{\circ}\text{C}$), and the vacuum-drying from the frozen state. Theoretically, if it is possible to cool a specimen quickly enough, water should be vitrified in place, in an amorphous state, and the potentially structure-damaging growth of ice crystals should not occur (Lawrence et al. 1979). The obtained data are given according to the following key (Tuncer 1988):

- e_1 : void ratio by bulk measurement.
- e_2 : void ratio by Hg injection.
- % total: percentage of total pore volume intruded by Hg.
- average ϕ (): average pore diameter.
- % large, medium or small: percentage of large ($>2\text{--}3$), medium or small (<0.05) pores.
- mode large (), medium () or small ($\text{\AA}$): mode of large, medium or small pores.
- unif. coef.: uniformity coefficient of pores ϕ_{40}/ϕ_{80}

Results

A detailed description of every experiment performed in the thermohydraulic cell is given in Annex I. The Annex includes the initial and final characteristics of the clay, the evolution of temperatures with time, the distribution of temperatures in clay at different times and the final distribution of properties of the clay (dry density, water content, free silica, chlorides, sulphates, specific surface). The isolines are calculated by a contouring routine.

Temperature distributions

In Fig. 2 two representative steady-state distribution of temperatures in the clay are shown.

Differences in local temperatures and temperature distributions produced by spraying the external surface of the cell with water clearly indicate the importance of the experimental boundary conditions. When the cell is surrounded by air, the thermal steady-state is reached some thirteen hours after the start of heating, regardless of the initial water content of the clay, the kind of heater or the hydration process. Cooling time, once the heater is disconnected, is longer, around twenty four hours. When the cell is covered by water at 30 $^{\circ}\text{C}$, external heat dissipation from the cell is more effective, and the temperatures of the clay are lower. Steady-state is reached much faster, about an hour after the commencement of heating. The geometry of isotherms is also different in both cases, as the heat flow through the steel wall is much greater when the cell is surrounded by water than when it is by air.

The temperature distribution is greatly influenced by the size and power of the heater used. The geometry of the isotherms varies according to the shape of the heater and the temperatures reached are much higher when the axial heater is used (compare the temperature distribution of Ex4 (T6) and Ex7 (T3) in Annex I).

The distribution of temperatures in experiments in which the initial water contents were 10.5, 15 and 20% is quite similar, the slight differences in values can be explained by those in the heater or room temperature. For the times recorded, the effect of hydration on the temperature is not detected either, as it can be seen in the figures relating to the evolution of temperatures registered by thermocouples as hydration proceeded in Ex8 (Annex I).

Hydration process

In Ex3 and Ex6, hydration with running water at 1 MPa took place since the beginning of the last heating cycle. In Ex8 and Ex9 heating and hydration with deionized water started at the same time. The evolution of water intake with time is shown in Fig.2. It should be outlined that the initial water content has a significant effect on the rate of hydration; being the higher the initial water content the slower the hydration rate. On the other hand, the geometry and size of the heater, and hence the magnitudes of local thermal gradients, do not seem to affect the overall hydration behaviour. Even in Ex10

(unfinished), in which no heating is taking place, the hydration rate is mainly influenced by the initial water content of the clay (20%) and is similar to that of Ex6 (19% initial w, small heater) or Ex9 (17% initial w, axial heater). Both facts could be explained by the high suction of montmorillonite, which is mainly controlled by the water content, being the value around 130 MPa for the clay at a water content of 11%, and decreasing to around 23 MPa when the water content goes up to 20% (see Section 3.2.1).

Hydration rates in these experiments have been fitted using a nonlinear regression technique to the analytical function ($Q = A - A \exp(-Bt^c)$) (Fig. 4), where Q (cm^3) is the uptake of water and A is the total uptake at infinite time. This function has been used successfully in processes where the measured parameter varies at slower rates as a function of time (for example, a sedimentation process; Stawinski et al. 1990). The function adequately describes the hydration rate behaviour over the periods of time considered. The calculated volume of water inflow at infinite time is higher than the one calculated for a 100% saturation considering 1.65 g/cm^3 as dry density. This fact implies the need of longer periods of time to achieve or predict a hypothetical steady state.

The swelling pressure evolution during hydration has been measured at 1 cm from the bottom in the wall of the cell in Ex8 (Fig. 3). A progressive increase is observed and the final value obtained is in close agreement with the range of swelling pressures determined in this clay between 25 and 100 °C at $1.5\text{--}1.6 \text{ g/cm}^3$ dry density (3–5 MPa; Rivas et al. 1991). Besides, Zhang et al. (1993) have shown that the interlayer spacing of a hydrated montmorillonite is independent of the temperature in the range of 10–40 °C, and thus, no serious effect should be expected in the hydration and swelling behaviour in response to the differences in the temperature gradient imposed.

Final water content and density distributions

At the end of each experiment the clay block is taken out and systematically cut to determine the water content and density at different points throughout the sample.

A clay block uniaxially compacted so as to display an average dry density of 1.65 g/cm^3 and not submitted to heating or hydration has an heterogeneous distribution of densities, which are higher in the upper part of the block, produced during the compaction process. The final dry

densities of Ex6 (small heater) and Ex8 (axial heater), show that the final distribution of dry densities, after hydration, can be explained by the compaction process, except close to the heater and at the bottom, where the densities are very low (see the figures relating to these experiments in Annex I). The average dry density must stay approximately constant during the experiment, although some elastic deformation of the steel walls could be expected due to the thermal stress and the swelling pressure developed by clay, specially in the longer experiments.

The water content isolines, both for experiments with and without hydration, are similar in form to the isotherms, which are mainly influenced by the heater dimensions. In Ex7, where the sample was heated to 100 °C for 241 hours during the last cycle and not hydrated, there has been some redistribution of water: the final water content (Annex I), which was originally 11.4%, has decreased to 8% near the heater, while it has slightly increased remote from the heater with values up to 13%. This effect is less evident when the small heater is used.

The influence of the initial water content on the final distribution of dry densities and water contents is clear, as it is shown in the figures relating to Ex6 and Ex8 (Annex I). The initial water content of Ex6 was 19.0%, corresponding to a saturation index (S_r) of 78%, while in Ex8 was the stabilization at room conditions water content (11.8%, $S_r=49\%$). Hydration was allowed to continue for 668 hours in Ex6 and 2402 hours in Ex8, the final saturation indexes being 87% and 82% respectively. The final water contents are not very different in both cases, except in the heater-affected area. In the lower part of the sample, the water content of Ex8 had increased from 12 to 28% (Fig. 5c), while for Ex6 the change was from 19% to 27% (Fig. 5a). For this reason, the lower part of the sample in Ex8 has undergone more swelling and density in this region is significantly lower than in Ex6.

Solute movement

Dissolved silica can be produced either by heat-induced dissolution of poorly ordered mineral phases or by the reaction of smectite to illite, this being enhanced at moderate to high temperatures (100–200 °C) or by wetting-drying cycles (Andreoli et al. 1989). Cementing processes can take place between the particles or clay aggregates where silica precipitates due to supersaturation. The spatial distribution of extractable silica shows that there is

not a significant trend in relation to the thermal gradient, although the axial heater experiment shows lower values close to the hydration source, i.e., the porous disc. Silica values are slightly higher in Ex6 (19% initial w: 250-1000 ppm) than in Ex8 (13% initial w: 100-300 ppm), the value for the natural clay being 90 ppm. It is deduced that the availability of free water from the beginning of the hydration process could be an important factor for the silica dissolution in the warm zones.

The electrical conductivity (EC) distribution in Ex6 and Ex8 reveals a clear relationship between the thermal gradient and salt migration and concentration. Both experiments indicate an enrichment of dissolved salts in the zones near the heater and leaching in the more hydrated zones. The electrical conductivity near the heater increases from 1.8 mS/cm, which is the normal value of this montmorillonite, to 3.5 mS/cm in Ex6 and to 6.8 mS/cm in Ex8 (see Annex I). On the contrary, in the lower part of the sample, where water comes in, electrical conductivity decreases to 0.9 mS/cm in Ex6 and to 0.6 mS/cm in Ex8. These trends in electrical conductivity correspond to the solute movement observed. EC correlates well with the Cl^- distribution, the initial concentration of which is 280 ppm. Chloride is easily dissolved and transported as the water front moves towards the unsaturated areas. Sulphate (270 ppm initial value), shows a quite distinct behaviour. Its short range of migration can be inferred from the low solubility of some common sulphate salts, like gypsum. This ion is depleted only in proximity to the hydration source, and is concentrated at the bottom end of the heater.

It must be pointed out that the salt concentration gradient will be developed immediately after the emplacement of the clay barrier, as it becomes saturated. The existence of an important saline environment near the heater would enhance the corrosion of the canister and probably cause a higher hydraulic conductivity. As Yong et al. (1992, pp. 197-198) have shown, clay samples leached with NaCl solutions show an increase in permeability as NaCl concentration increases. These authors have stressed that the increase in permeability could be attributed to the significant decrease in repulsive interparticle forces, due to the increase of cation concentration in the pore fluid. Besides, high salt concentration prevents the free swelling developed by Na-homoionized smectites in low concentrated electrolytes, restricting the interlayer spacing to 15-17 Å (2-3 layer hydrate) when salt concentration (NaCl) reaches values above 1.5-2 m (Slade et al. 1991).

Conclusions

Although the experiments have not yet finished and more time is needed to fully understand the behaviour of water and solutes in compacted bentonite submitted to thermal gradients and its effects, the following conclusions can be extracted:

- The sample takes around 13 hours to reach a steady state of temperatures after the heating has started, without any noticeable influence of the initial water content or kind of heater. Cooling times are much longer, almost 24 hours.
- If the thermostatic bath is on (a warm water running sheet), the distribution of temperatures is different and the temperatures reached are lower. This is caused by the greater thermal conductivity of water with respect to air. The steady state is attained much quicker, one hour after heating has started.
- The distribution of temperatures in a clay block depends strongly on the geometry and power of the heat source. It seems to be independent of the water content of clay, at least in the range studied: from 10 to 20%. The boundary conditions, i.e., the thermal conductivities of the surrounding material, greatly modify the temperatures reached and their distribution.
- For the periods of time considered (up to 2500 hours), the hydration process is not affected by the thermal gradient, but by the initial water content of the clay, being slower when the initial water content is higher. The high suction of montmorillonite, i.e., its avidity for water, which decreases as it becomes wetter, accounts for this fact.
- The final water content distribution is related to the thermal gradient. The entrance of water produces an increase in water content and, consequently, a density decrease due to swelling. The swelling pressure developed produces a density increase in adjacent areas, the average dry density remaining constant.
- There is not a significant concentration of free silica in the clay in any of the experiments; for this reason, no cementation processes are supposed to have occurred. The availability of free water from the beginning of the experiment could be an important factor for the silica dissolution in the warm zones.
- There is an important saline environment near the heater due to salt migration towards the dried areas, with a different behaviour of chlorides and sulfates. This zone would have a di-

different physico-chemical and mechanical behaviour as saturation proceeds and the corrosion of the canister would be enhanced.

3.1.2 Alteration cell

Description of the cell and experiments

Fig. 4 shows a schematic representation of the alteration cell. A teflon wall has been placed between the clay and the steel carcass in order to avoid the heat transmission through the sides. A previously compacted sample of clay is placed in and heated to 150 °C at the bottom and hydrated with distilled water under a pressure of 10 bar at the top. Sample dimensions are 7.8 cm height and 3.8 cm diameter. The clay has been extracted after different periods of testing for each experiment. The determinations explained in Section 2.1.1 have been done at different parallel levels of the sample. A theoretical distribution of temperatures in the cell is shown in Fig. 5. It has been obtained with ANSYS, a finite element code, assuming thermal conductivities of 0.8 for clay, 0.3 for teflon, 3.6 for the porous stone and 15 W/mK for the steel. The parallelism of the isotherms is remarkable.

Results

Several experiments of different duration (Ex1 to Ex11) have been performed in this cell with montmorillonite S-2 with dry density 1.65 g/cm³ and stabilized water content. The measured final parameters, including mercury porosimetry data, are shown in Annex II. There is an even final water content around 21% ($S_r=1$ for $w=25\%$) in all the experiments except in the shorter ones, in which the water content distribution is still influenced by the thermal gradient (Fig. 6). From Ex9 on, the teflon wall must have lost its sealing ability, and final water contents are very low, as water is evaporating probably through the lower part.

In all the experiments a significant increase of electric conductivity towards the heating surface has been observed. Chlorides and sulfates have been quantified in the 1+5 extract used to measure conductivity. Fig. 7 and 8 show the final concentration of chlorides and sulphates at different levels of the sample for experiments of various durations. No significant movement of free silica has been observed.

The external specific surface (BET) decreases towards the heated end. This is a general observation in all the experiments, even in the shortest ones, and

could be attributed to an increase in montmorillonite crystal size.

In those experiments long enough (more than 10 days), the mercury porosimetry data show an increase of the total percentage of voids intruded by mercury, a decrease of small pore percentage and an increase in the uniformity of pore sizes.

Discussion

There is a differential behaviour of Cl^- (Fig. 7) and SO_4^{2-} (Fig. 8) as a function of time. In the short term experiments, chloride is leached by the injected water as hydration is taking place, increasing its concentration towards the hot end. As saturation is completed, what happens around 40 days after the beginning of hydration (Fig. 6), chloride starts to diffuse backwards (to the hydration surface), in order to regain an homogeneous profile of concentration, what has almost been achieved in the 108 days duration experiment (Ex1). On the contrary, sulphate concentration remains virtually constant through the whole sample in the short experiments, and is only after complete saturation that sulphate starts to concentrate in the warm zone. This aspect can be originated by precipitation of soluble sulphates in the "more concentrated" warm zones.

The mercury porosimetry data correlates well with the observed BET diminution towards hot areas. As montmorillonite recrystallizes, increasing its crystal size, the percentage of small pores diminishes, increasing the uniformity between pore sizes and allowing mercury to intrude in a greater percentage of pores, as the smallest ones (those under 0.003 μm) are not intruded by mercury. As a result, the difference between void ratio obtained by bulk measurement and that obtained with data from mercury porosimetry is less important.

3.2 Suction controlled tests

Both for the determination of the relation between water content and suction as for the oedometer tests, the suction is controlled by two different methods: air pressure (Escario 1969) and control of the relative humidity in a vacuum closed atmosphere by sulfuric acid solutions (Biarez et al. 1988).

The theoretical concept of both methods is something different. If suction changes are given by the difference between pore air pressure and pore water pressure ($s=u_a-u_w$), by applying air pressure to the sample we introduce an increase in u_a , while u_w remains equal to the atmospheric pressure. Thus,

suction varies in the same quantity that nitrogen pressure does. In the second method, the relative humidity of the atmosphere in which the sample is placed, controls u_w and u_a , as there is no external exchange.

Air pressure method

In the air pressure method, the compacted sample is placed in a stainless steel pressure cell (Fig. 9) in contact with a dialysis membrane which is permeable to water but not to air (Escario & Sáez 1973). The membrane is in contact with free water at atmospheric pressure. The pressure in the cell is immediately raised by injecting nitrogen to the desired value, which increases the air pressure in the pores of the clay. This new pressure situation forces the clay to exchange water through the membrane until equilibrium is reached again.

To remove the air bubbles that diffuse through the membrane, a pump is located between the cell and the water deposit, in order to circulate water in contact with the membrane, as it was suggested by Bishop & Donald (1961).

Because of the mechanical limitations of the cell, this method is fitted only for suction pressures below 14 MPa.

Sulfuric acid solutions method

The samples are introduced in a closed atmosphere -vacuum desiccator for the determination of the water content vs suction curve, or hermetic cell showed in Fig. 10 for the oedometer tests (Esteban 1990)-, in which a known relative humidity is imposed by a sulfuric acid solution of a given density. The pressure in the pores of the sample is related to the water activity of the solution by Kelvin's Law. The clay exchanges water until it reaches a thermodynamic equilibrium with the vapour pressure of the solution.

The relation between the activity of the solution and the weight percentage of H_2SO_4 used to prepare it, is reflected in experimental tables (Gmitro & Vermeulen 1964). This relation depends on temperature, therefore, it is necessary to keep it constant during the tests. In Fig. 11 this relation is shown for temperatures of 20 °C and 70 °C. There is also an experimental relationship between acid weight percentage in the solution and solution density (Weast 1989). The water transfer between clay and atmosphere makes the density of the solution vary during the stabilization period. For this

reason, the solution densities are checked with picnometers before and after the experiment, in order to know the actual suction pressure to which the sample has been submitted. Suction pressures from 13 to 300 MPa can be obtained with this method.

3.2.1 "Water content vs suction" curve

Experimental technique

For the determination of the relation between water content of the clay and suction, samples of different initial dry densities (1.55 to 1.95 g/cm³) and water contents (natural, 15 and 20%) have been uniaxially compacted, their diameter being 3.03 cm and their height 1.23 cm. They are introduced either in the pressure cells described above (one sample in each cell) or in a vacuum desiccator with a sulfuric acid solution (5 to 12 samples inside each desiccator, to avoid a major change in solution density after stabilization).

The water content of the samples is checked every week by weighting them, taking as stabilization criterium a weekly oscillation of the water content less than 1%. As the samples can change their volume freely during the experiment, the dimensions of the sample are measured at the end of the stabilization process. With these final values we are able to plot the "water content vs suction" curve, slightly different for each initial water content. Most of the determinations have been done at 20 °C, although some values have been determined at 70 °C, by introducing the vacuum dessicators in an oven.

Results

The relation between suction pressure and water content has been determined at 20 °C for montmorillonite with different initial water contents and dry densities. The major percentage of water exchange is accomplished in the first week, but a good stabilization in water content values is not achieved until one-two months later.

There is a logarithmic relationship between water content at equilibrium and suction. Some of the obtained curves are shown in Fig. 12. The final water content at a given suction seems to be independent of the initial dry density or water content of the clay. This could be due to the fact that the high range of suctions considered affects the microporosity of clay, which is independent of dry density (Volckaert, per. com.). The relation between water content (w , %) and suction (s , MPa) can be expressed for montmorillonite as:

$$w = 36.0 - 5.1 \ln(s) \text{ (151 values, } r^2 = 0.953 \text{)}$$

From these curves we obtain the suction pressure value for each water content, i.e., the suction for which the initial water content in the clay does not change during the experiment. The suction values obtained are: 133 MPa ($w=11\%$), 61 MPa ($w=15\%$) and 23 MPa ($w=20\%$).

A good correlation has been found between the values obtained in membrane cells and in sulfuric acid dessicators. This suggests that the osmotic suction is irrelevant in these clays with respect to the matric one, as the membrane method does not control the osmotic suction.

The values obtained at 70 °C do not differ much of those obtained at 20 °C, being the water contents slightly inferior for the same suction.

3.2.2 Suction controlled oedometer tests

Experimental technique

The oedometer tests are performed in oedometer apparatus, in which the standard cell has been replaced by a pressure cell or by a hermetic sulfuric acid solution cell (Fig. 9 and 10). In a conventional oedometer test the sample is contained within a rigid circular metal ring, which prevents any radial strain, and it is loaded from top and bottom by rigid platens of porous discs. The axial stress is varied in a stress-controlled manner by changing the weights on a hanger supported by the top platen. The axial strain is measured using a dial gauge. In the modified cells used in the tests reported here, suction can also be controlled. Again, the methods used for controlling suction have been nitrogen or sulfuric acid solutions, the first one for the range of suctions between 0.1 MPa to 14 MPa, and the second one for the range between 13 and 140 MPa. Five oedometers of each type are available. The clay has been uniaxially compacted under a pressure of 20 MPa to a dry density of 1.60 g/cm³ with a water content of approximately 11%, the height of the sample being 0.6 cm and the diameter 4.95 cm. The initial void ratio is 0.737 and saturation index 0.47.

The stress paths of the oedometer tests have been suggested by the UPC Group. Successive steps of a given vertical load (p) and suction (s) are followed, ranging the vertical load applied between 0.05 and 5 MPa, and the suction pressure between 0.1 and 14 MPa in the pressure cells and from 13 to 130 MPa in the sulfuric acid cells. As the stabilization process until no deformation is registered is very long, the

duration of each step has been fixed to 20 days, a period that we consider enough to achieve the main percentage of total deformation in most of the cases.

The first set of oedometer tests have consisted on a dessication-hydration cycle at constant vertical load, different for each test, starting with a suction pressure of 0.1 MPa in nitrogen cells and 13 MPa in sulfuric acid cells. This cycle is followed by a loading-unloading cycle at constant suction pressure of 0.1 MPa in nitrogen cells and 100 MPa in sulfuric acid solution cells. The second set of oedometer tests, which is still taking place, consist on a hydration-dessication cycle at the same constant vertical loads of the previous tests, the initial suction being 14 MPa in nitrogen cells and 130 MPa, which is the suction value for montmorillonite with stabilized water content, in sulfuric acid cells. Afterwards, a loading-unloading cycle at constant suction pressure of 14 MPa in nitrogen cells and 130 MPa in sulfuric acid cells is performed.

In the oedometer cells, a peristaltic pump is used to circulate water in contact with the membrane and remove the air bubbles, and the water deposit is a buret in which water taken or given by the sample can be directly measured. Over the water surface in the buret an oil layer avoids evaporation. Unfortunately no coherent values have been obtained by direct reading of the water volume in the buret, probably due to some unknown leak. In the sulfuric acid cells an attempt has been made of calculating the water volume change in the sample by measuring the density variation in the sulfuric acid solution at the beginning and at the end of each step, and assuming that the density variation is due to the water taken or given by the clay. No good results have been obtained.

From the point of view of the experiment performance, the manipulation of the sulfuric acid cells is much easier than that of the nitrogen cells. Working with air pressure implies the needing of a supplementary load to compensate the outward displacement of the loading ram. The pressure inside the cell tends to decrease with time, and it has to be periodically elevated, what produces minor deformations of different sense in the sample. Serious breakdown may happen by membrane failure, what produces a sudden decrease of air pressure. The existence of the membrane made necessary a previous calibration of its deformation, which, once performed, has shown that the deformation of the membrane is negligible with respect to that of the clay.

Once the sample is dismantled direct determinations of dry density and water content are made (Annex I), and half of the sample is liophilized for mercury porosimetry, as it is explained in Section 3.1.1.

A nitrogen pressure oedometer with temperature control has been designed, constructed and tested, and is currently working, although results are not yet available.

Results and Discussion

In Annex III a detailed description of each experiment is given: initial and final data of the sample, stress path followed in a p (vertical load)- s (suction) space, final void ratios attained and consolidation curves. The void ratios attained by the samples at the end of each step of both cycles of the two set of tests are plotted in Fig. 13 to 16. Mercury porosimetry data of all the finished tests are gathered in Table III, beside the data for a sample of montmorillonite compacted with the same characteristics of those of the oedometer tests but not tested.

In general, once suction is changed, by changing the sulfuric acid dissolution or the nitrogen pressure, the effect on sample deformation is not appreciable until 3-5 hours later, and is not remarkable until 24 hours later. When the sample is externally loaded, the larger deformations are registered between 10 minutes and 1 hour in the nitrogen cells, but in the sulfuric acid cells the consolidation is rather continuous and long. After 10 days the deformations are usually minor. For most of the steps, deformations have almost ceased after 20 days, which is the fixed duration. In test EDN5_1, in which the duration of the steps was 100 days, the suitability of the fixed duration (20 days) was demonstrated, as most of the deformation is accomplished in this time.

In the first set of tests in the nitrogen cells (Fig. 13) the void ratios at the end of the first step are very high, as the initial vertical loads and suction pressures were not enough to counteract the high swelling pressure of montmorillonite. During the dessication process, consolidation starts to be important at lower suctions for the samples with a small vertical load; as vertical load is higher, significative diminution of void ratio starts later. The hydration line is rather similar for all the tests. Once the dessication-hydration cycle is completed, the final void ratio is better recovered in the samples with greater vertical load. In the following loading-unloading cycles consolidation is more important in those samples with a small previous

vertical load. The unloading line is similar in all the cases and the void ratio is completely recovered. Thus, consolidation by suction increase seems to be less reversible than that by vertical loading.

However this is not the case of the first set of tests in the sulfuric acid cells (Fig. 14). During the dessication cycle consolidation is much more important than in the case of nitrogen cells, as suctions are greater, despite of the higher initial void ratio of the samples in nitrogen cells. During the loading process the consolidation is smaller for the samples with a high previous load, and in general, is less important than in the case of nitrogen cells, as the soil stiffness against external loading increases with suction (Alonso et al. 1987, 1990). The final void ratios are smaller for the samples in sulfuric acid cells, as they have been submitted to greater suctions during the dessication process.

The mercury porosimetry data give greater void ratios for the samples in sulfuric acid cells, i.e., a greater percentage of the void volume is intruded by mercury in the case of sulfuric acid cells (Table III). This is because the samples in nitrogen cells have a greater percentage of small pores, which cannot be intruded by mercury; these small pores have disappeared in the case of sulfuric acid cells. During the dessication process in the sulfuric acid cells, the high suctions affect specially the microporosity, and in the nitrogen cells, the suction values, which are lower, affect both the macro and the microporosity. This could be the reason why in the case of nitrogen cells the recovery after a dessication-hydration cycle is less effective than in the case of sulfuric acid cells, as in the first case the consolidation is affecting macropores (Gens & Alonso, 1991). Anyway, after the completion of both kind of tests, the level more affected is that of the medium pores, which suffer the greater reduction in percentage with respect to the untested sample (Table III). It should be pointed out that, for the range of suctions of these tests, the microstructural level must remain saturated, as water contents below 8% are not expected (according to the suction-water content curve for montmorillonite of Section 3.2.1.), and 8% is the value above which all the primary adsorption positions are occupied (adsorption isotherms, Rivas et al. 1991).

In the second set of oedometer tests the samples were submitted first to a hydration-dessication cycle. The swellings are greater for the samples in nitrogen cells, in which the suction pressures are lower. In both kind of tests the vertical load applied seems to be the determinant factor in the reversibility of the

deformation: as the vertical load is higher, the sample swells less during the hydration process and during the dessication process the ancient void ratio is best recovered or, for the higher loads, even reduced. This can be explained by the fact that the proportion of macrostructural irreversible strains caused by the expansion of the microstructure increases as the value of p/p_0 reduces (Gens & Alonso 1991). For a vertical load of 5 MPa and an initial suction pressure of 14 MPa (EDN5_2) the sample suffers hardly any deformation during the hydration-dessication cycle. For a vertical load of 5 MPa and an initial suction pressure of 130 MPa (EDS3_2), the sample collapses as suction decreases to 30 MPa. The magnitude of the deformation by collapse is not very large, but afterwards, during the dessication, the sample consolidates easily. After the hydration-dessication cycle at 130 MPa (sulfuric acid oedometers) the samples seem to have been stiffened and no significant deformations are registered during the loading-unloading cycle.

3.3 Triaxial tests

To know the unsaturated failure parameters of the material, some triaxial tests have been performed. The triaxial test consists on the application of a vertical load (σ_1) to a series of samples of the same initial dry density, submitted to different confining pressures ($\sigma_3 = \sigma_2$), while stress and strain are registered until failure. Due to the difficulty of performing triaxial tests under controlled or imposed suction, specially on high suction materials as montmorillonite S-2, the tests have been performed on conventional triaxial cells, in which no control of suction is taken.

Experimental technique

The clay is prepared by uniaxial compaction of a cylindrical probe to a given dry density. The dimensions of the compacted sample are 11.52 cm² surface and 7.8 cm height. The water content of the clay prior to compaction has been varied from the stabilization one (around 11%), to 20%, and maintained constant during all the tests, i.e., the sample remains unsaturated, although the value of the suction is only known with certainty at the beginning of the tests. As the sample is consolidated and sheared the evolution of the suction value is unknown (although density does not seem to modify the relationship between water content and suction for this clay in the range of densities considered

(Section 3.2.1.), the effect of loading on suction has not been studied).

The tests start by the consolidation of the sample under a pressure σ_3 which is maintained constant during the shear process. The consolidation time has been fixed to 7 days. The sample is not previously saturated. The confining pressures used have been grouped in three ranges: low, between 0.5 and 3 MPa, medium, between 4 and 10 MPa, and high, between 10 and 40 MPa. These are the ranges that had been used in the previous CD tests, in which high confining pressures were needed to prevent the swelling of the sample during saturation.

During consolidation and shear the top and bottom valves for pore pressure remain open to the atmosphere. Neither the pore-air pressure nor the pore-water pressure are measured. The deviator stress is applied slowly in order to prevent the development of excess pore pressure in the soil. The constant strain rate has been 1% in around 460 minutes. This rate was determined in CD saturated tests performed in this montmorillonite, following Gibson & Henkel (1954) procedure.

Results

Tests have been performed with montmorillonite of initial dry density 1.65 g/cm³ and water contents of 11, 15 and 20%. The results are plotted in Fig. 17 as $(\sigma^3 - \sigma_1)/2$ vs $(\sigma_3 + \sigma_1)/2$ at failure. Straight lines ($y = a + bx$) can be adjusted for every range of confining pressures (low, medium, high), from which we obtain the parameters of cohesion (a) and friction angle ($\arctan b$). These values are shown in Table IV. The cohesion values obtained with this method are slightly lower than those obtained graphically from Mohr's circles.

Another set of tests has been performed with montmorillonite with different initial dry densities and initial water content between 9 and 12% (the stabilization one). The results are plotted in Fig. 18 as $(\sigma^3 - \sigma_1)/2$ vs $(\sigma_3 + \sigma_1)/2$ at failure. The cohesion and friction angles (Table V) have been obtained in the way explained above.

In both set of tests, as confining pressure increases, friction angle decreases and cohesion increases, which correspond to the curvature of Mohr's envelope. As the sample becomes saturated, for the same initial dry density, the strenght of the sample decreases and hence, the failure parameters (Table IV).

Typical stress-strain curves of this kind of tests show an increase in the maximum deviator stress (q

$= \sigma_3 - \sigma_1$) as the confining pressure is increased. The curves become horizontal where q reaches a limiting value and the samples fail by continuing to strain without further change of stress. Only for the low range of confining pressures and for the higher densities, a stress peak is observed. The strain at failure is below 8% in the range of low σ_3 , and not far from 20% in the range of high σ_3 .

3.4 Thermal conductivity

New determinations of superficial thermal conductivity (λ_T) have been done, due to the interest of this parameter for the thermal modelling. A Quick Thermal Conductivity Meter Kemtherm QTM-D3 of Kyoto Electronics has been used. The principle of the measure is based on the transient hot wire method. Samples of different water content and dry density have been tested. The values obtained are shown in Table VI. In Fig. 19 these values are plotted and a bivariate (dry density and water content) logarithmic estimation of thermal conductivity is proposed. Thomas et al. (1994) have described the thermal conductivity of montmorillonite S-2 by fitting a standard curve to the measured experimental data:

$$\lambda_T = 0.62 + 3.976 Sr + 2.687 Sr \ln(Sr) - 3.313 (Sr)^2$$

where Sr is the degree of saturation of liquid content.

3.5 Influence of temperature on hydraulic conductivity

Hydraulic conductivity measures performed at different temperatures were done in montmorillonite three years ago (Rivas et al. 1991). The values obtained for two different densities have been revised and are plotted in Fig. 20. The increase of hydraulic conductivity with temperature has been explained by the decrease of water cinematic viscosity (Rivas et al. 1991).

3.6 Interstitial water

The extraction of interstitial water from clays is a difficult task because of their avid for it. We have done a bibliographic research on the methods normally considered, that are (Rodríguez & Manzano 1988):

- Displacement by ultracentrifugation of the clay previously mixed with an immiscible liquid like carbon tetrachloride, tetrachloroethylene, FC70 or 1,1,1-trichloroethane (Mubarak & Olsen 1976).
- Compaction at high pressure using a squeezer (Kalil & Goldhaber 1973, Manhein 1974). A recent application of this method can be found in Entwisle & Reeder, 1993.
- Compaction of the sample mixed to a immiscible liquid (Kittrick 1983).

A "squeezing device", that allows the compaction of the sample to 100 MPa, has been constructed and is now under testing. A schematic diagram of it can be found in Fig. 21.

Acknowledgements: This research program has been carried out within the context of CEC (Commission of the European Communities) Contract FI2W-CT91-0102(DOEO) "Modelling and validation of the thermal-hydraulic-mechanical and geochemical behaviour of the clay barrier". It has been partially supported by ENRESA. We acknowledge the Department of Chemical Engineering of UCM (Madrid Complutense University) for the collaboration in the experimental work relating to the thermohydraulic cell. We thank Mr. J. Sáez (CEDEX) for his useful advises on suction control techniques and Mr. E. Alonso's research group (DIT-UPC, Barcelona) for their suggestions on the development of the oedometer tests. The laboratory work has been mostly performed by Ms. A. Pelayo.

4

REFERENCES

$= 0.5-0.7$ as the confining pressure is increased. The curves become horizontal where q reaches a limiting value and the samples fail by continuing to strain without further change of stress. Only for the low range of confining pressures and for the higher densities, a stress peak is observed. The stress at failure is below 8% in the range of low σ'_v and over 30% in the range of high σ'_v .

3.4 Thermal conductivity

New determinations of mineral thermal conductivities (K) have been made, due to the change of this parameter for the thermal conductivity. A new Thermal Conductivity Scale (Kamath 1974, 1975) of Kyushu Institute has been used. The principle of the measure is based on the transient hot wire method. Samples of different water content and density have been tested. The values obtained are plotted in Table VI. In Fig. 19 these values are plotted and a bivariate dry density and water content (porosity) estimation of thermal conductivity is proposed. Thomas et al. (1994) have developed the thermal conductivity of metagranulite 5.2 by using a standard curve to the measured experimental data:

$$k_T = 0.62 + 1.876 S_r + 2.687 S_r \ln S_r, \quad (24)$$

where S_r is the degree of saturation of liquid content.

3.5 Influence of temperature on hydraulic conductivity

Hydraulic conductivity measurements performed at different temperatures were done in 1950s and 1960s (about 1950-1960). The values obtained for two different densities have been revised and are plotted in Fig. 20. The increase of hydraulic conductivity with temperature can be explained by the decrease of water viscosity (Rivas et al. 1991).

3.6 Interstitial water

The extraction of interstitial water from clays is a difficult task because of their low porosity. We have used a differential method on the samples normally consolidated (see Fig. 18) (Rivas et al. 1991).

The extraction of water from clays is a difficult task because of their low porosity. We have used a differential method on the samples normally consolidated (see Fig. 18) (Rivas et al. 1991).

The extraction of water from clays is a difficult task because of their low porosity. We have used a differential method on the samples normally consolidated (see Fig. 18) (Rivas et al. 1991).

The extraction of water from clays is a difficult task because of their low porosity. We have used a differential method on the samples normally consolidated (see Fig. 18) (Rivas et al. 1991).

The extraction of water from clays is a difficult task because of their low porosity. We have used a differential method on the samples normally consolidated (see Fig. 18) (Rivas et al. 1991).

The extraction of water from clays is a difficult task because of their low porosity. We have used a differential method on the samples normally consolidated (see Fig. 18) (Rivas et al. 1991).

Acknowledgments—The authors thank the following institutions for their financial support: the Spanish Ministry of Education and Science, the Spanish Ministry of Energy and the Spanish Ministry of the Environment. The authors also thank the following institutions for their financial support: the Spanish Ministry of Education and Science, the Spanish Ministry of Energy and the Spanish Ministry of the Environment. The authors also thank the following institutions for their financial support: the Spanish Ministry of Education and Science, the Spanish Ministry of Energy and the Spanish Ministry of the Environment.

References—Alonso, E., Gens, A., and Pineda, J. M. (1990). "Thermal conductivity of clays." *Journal of Geotechnical Engineering*, 116(10), 1155-1165. Kamath, K. R. (1974). "Thermal conductivity of clays." *Journal of Geotechnical Engineering*, 100(10), 1155-1165. Kamath, K. R. (1975). "Thermal conductivity of clays." *Journal of Geotechnical Engineering*, 101(10), 1155-1165. Rivas, J. M., Alonso, E., and Gens, A. (1991). "Thermal conductivity of clays." *Journal of Geotechnical Engineering*, 117(10), 1155-1165.

- ALONSO, E.E.; GENS, A. & HIGHT, D.W.(1987): Special problem soils. General report. Proc. 9th European Conf. Soil Mech. Found. Engng. 3: 1087-1146, Dublin.
- ALONSO, E.E.; GENS, A. & JOSA, A.(1990): A constitutive modelling for partially saturated soils. *Géotechnique* 40: 405-430.
- ANDREOLI, C.Y.; ROBERT, M. & PONS, C.H.(1989): First steps of smectite-illite transformation with humectation and dessication cycles. *Applied Clay Science* 4: 423-426.
- BIAREZ, J.; FLEUREAU, J-M.; ZERHOUNI, M-I. & SOEPANDJI, B.S.(1988): Variations de volume des sols argileux lors de cycles de drainage-humidification. *Revue Française de Géotechnique* 41: 63-71.
- BISHOP, A.W. & DONALD, I.B.(1961): The experimental study of partially saturated soils in the triaxial apparatus. Proc. 5th Int Conf. Soil Mechanics 1: 13-21.
- ENTWISLE, D.C. & REEDER, S.(1993): New apparatus for pore fluid extraction from mudrocks for geochemical analysis. In: MANNING, D. A.C. ; HALL, P.L. & HUGHES, C.R.(eds): *Geochemistry of clay-pore fluid interactions*. Chapman & Hall. London. 365-388.
- ESCARIO, V.(1969): Swelling of soils in contact with water at a negative pressure. Proc. 2nd Int. Conf. Expansive Clay Soils, pp. 207-217. Texas, A&M University.
- ESCARIO, V. & SAEZ, J.(1973): Measurement of the properties of swelling and collapsing soils under controlled suction. Proc. 3rd Int. Conf. Expansive Soils 2: 195-200. Haifa.
- ESTEBAN MORATILLA, F.(1990): Caracterización experimental de la expansividad de una roca evaporítica. Identificación de los mecanismos de hinchamiento. Tesis Doctoral. Universidad de Cantabria, Santander.
- GENS, A. & ALONSO, E.E.(1991): Behaviour of unsaturated active clays. Workshop on Stress Partitioning in Engineered Clay Barriers. AECL. Duke University, Durham, NC.
- GIBSON, R.E. & HENKEL, D.J.(1954): Influence of duration of tests at constant rate of strain on measured 'drain' strength. *Géotechnique* 4: 6-15.
- GMITRO, J.I. & VERMEULEN, T.(1964): A. I. Ch. E. J. 10(5): 740.
- KALIL, K.E. & GOLDBERGER, M.(1973): A sediment squeezer for removal of pore water without air contact. *Jour. Sed. Petrol.* 43: 553-557.
- KITTRICK, J.A.(1983): Accuracy of several immiscible displacement liquids. *Soil Sci. Am. J.* 47: 1045-1047.
- LAWRENCE et al.(1979): Pore size distribution in critical point and freeze dried aggregates from clay sub soil s. *J. Soil Science* 30: 499-516.
- MANHEIN, F.T.(1974): Comparative studies on extraction of sediment interstitial waters: Discussion and comment on the current state of interstitial water studies. *Clays and Clay Minerals* 22: 337-343.
- MUBARAK, A. & OLSEN, R.A.(1976): Immiscible displacement of the soil solution by centrifugation. *Soil Sci. Soc. Am. J.* 40: 329-331.
- PEREZ DEL VILLAR, L.; de la CRUZ, B. & COZAR, J.S.(1991): Estudio mineralógico, geoquímico y de alterabilidad de las arcillas de Serrata de Níjar (Almería) y del Cerro del Monte (Toledo). CIEMAT-DT-TG Internal Report. 51 pp. Madrid.
- PUSCH, R. & BORGESESSON, L.(1989): Bentonite sealing of rock excavations. OECD-NEA/EC Workshop Sealing of Radioactive Waste Repositories. Braunschweig.
- RIVAS, P.; VILLAR, M.V.; CAMPOS, R.; PELAYO, M.; MARTIN, P.L.; GOMEZ, P.; TURRERO, M.J.; HERNANDEZ, A.I.; COZAR, J.S. & MINGARRO, E.(1991): Caracterización de materiales de relleno y sellado para almacenamiento de residuos radioactivos: bentonitas españolas. CIEMAT-DT-TG Internal Report. 196 pp. Madrid.
- RODRIGUEZ, F.J. & MANZANO, M.(1988): Extracción de la solución intersticial en muestras de terreno poco permeable. In: QUERALT, R.(ed): *Aguas subterráneas, instrumentación, medida y toma de muestras*. Tecnología del Agua. Prensa XXI. pp. 357-379. Barcelona.
- SLADE, P.G.; QUIRK, J.P. & NORRISH, K.(1991): Crystalline swelling of smectite samples in concentrated NaCl solutions in relation to layer charge. *Clays and Clay Minerals* 39: 234-238.

4. References

- SMITH, B.F.L. & MITCHELL, B.D.(1987): Characterization of poorly ordered minerals by selective chemical methods. In: WILIS ON, M.J.(ed): A handbook of determinative methods in clay mineralogy. pp. 275-292 . Blackie & Son Ltd.
- STAWINSKI, J.; WIERZCHOS, J. & GARCÍA-GONZÁLEZ, M.T.(1990): Influence of Calcium and Sodium concentration on the micro structure of bentonite and kaolin. *Clays and Clay Minerals* 38: 617-622 .
- THOMAS, H.R.; HE, Y.; RAMESH, A.; ZHOU, Z; VILLAR, V. & CUEVAS, J.(1994): Heating unsaturated clay -An experimental and numerical investigation. 3rd European Conference on Numerical Methods in Geomechanics.
- TUNCER, E. R.(1988): Pore size distribution characteristics of tropical soils in relation to engineering properties. 2nd Inst. Conf. on Geomechanics in Tropical Soils 1: 63-70. Singapore.
- VILLAR, M.V. & MARTÍN, P.L.(1993): Suction controlled oedometer tests in montmorillonite clay. In: S.P. Bentley (Editor): *The Engineering Geology of Waste Storage and Disposal*. Preprints of Papers for the 29th Annual Conf. of the Eng. Gr. of the Geol. Soc. London, pp. 337-342. UWC Cardiff.
- VILLAR, M.V. & RIVAS, P.(1994): Hydraulic properties of montmorillonite-quartz and saponite-quartz mixtures. *Applied Clay Science* 9:1-9.
- WEAST, R.C.(Ed)(1989): *CRC Handbook of Chemistry and Physics*. CRC Press Inc. 2488 pp. Boca Raton FL.
- YONG, R.N.; BOONSINSUK, P. & WONG, G.(1986): Formulation of backfill material for a nuclear fuel waste disposal vault. *Canadian Geotechnical Journal* 23: 216-28.
- YONG, R.N.; MOHAMED, A.M.O. & WARKENTIN, B.P.(1992): Principles of contaminant transport in soils. *Developments in Geotechnical Engineering* 73. Elsevier.
- ZHANG, F.; ZHANG, Z.Z.; LOW, P.F. & ROTH, C.B.(1993): The effect of temperature on the swelling of montmorillonite. *Clay Minerals* 28: 25-31.

5

TABLES

SMITH, B.F.L. & MITCHELL, B.D. (1987). Characterization of poorly ordered minerals by selective chemical methods. In: WILIS, G.N. M.J. (ed.) *A handbook of descriptive methods in clay mineralogy*, pp. 27-57. Blackie & Son Ltd.

STAWINSKI, J., WIERZCHUK, I. & GARCIA-GONZÁLEZ, M.I. (1996). Influence of Calcium and Sodium concentrations on the structure of lamellar and basal. *Clay Miner. Clay Miner. Soc. J.*

THOMAS, D.P., DEY, S., CHAND, A., CHEN, S., HILL, V. & CHILFAR, R. (1988). The structure of clay and carbonates: an example of the relationship between structure and physical properties. *Clay Miner. Clay Miner. Soc. J.*

TUNICK, E. R. (1988). The clay mineralogy of the Tropic of Cancer. *Clay Miner. Clay Miner. Soc. J.*

VILLAR, M.V. & MARTIN, J. (1987). The clay mineralogy of the Tropic of Cancer. *Clay Miner. Clay Miner. Soc. J.*

Proceedings of Papers for the 20th Annual Conference of the Clay Mineral Society, 1983, pp. 1-10. Blackie & Son Ltd.

VILLAR, M.V. & MARTIN, J. (1984). The clay mineralogy of the Tropic of Cancer. *Clay Miner. Clay Miner. Soc. J.*

VILLAR, M.V. & MARTIN, J. (1984). The clay mineralogy of the Tropic of Cancer. *Clay Miner. Clay Miner. Soc. J.*

VILLAR, M.V. & MARTIN, J. (1984). The clay mineralogy of the Tropic of Cancer. *Clay Miner. Clay Miner. Soc. J.*

VILLAR, M.V. & MARTIN, J. (1984). The clay mineralogy of the Tropic of Cancer. *Clay Miner. Clay Miner. Soc. J.*

TABLES

TABLE I
CHARACTERISTICS OF THE EXPERIMENTS PERFORMED IN THE THERMOHYDRAULIC CELL.

Ex #	Heater	Total time (hours)	Number of heating-cooling cycles	Heating time (hours)	Hydration time (hours)
3	1 cm long	3579	4	2859	2475
4	"	808	10	316	No
5	"	861	4	637	No
6	"	1468	12	910	668
7	Axial	747	4	445	No
8	"	2402	1	2402	2402
9	"	4062	1	4062	4062

Ex4 to Ex6 had a external water shower at 30 C during some heating cycles.

Hydration in Ex3 and Ex6 took place since the beginning of the last cycle.

TABLE II
PHYSICAL PROPERTIES OF CLAY IN EACH EXPERIMENT PERFORMED IN THE THERMOHYDRAULIC CELL.

Ex #	Init. ρ_d (g/cm ³)	Init. w (%)	Initial Sr (%)	Water uptake (cm ³)	Final w (%)	Final Sr (%)	Final ρ_d (g/cm ³)
3	1.65	10.1	41	357	20.0	81	
4	1.62	12.4	48	0	13.1	51	1.62
5	1.65	15.0	61	0	16.2	66	1.63
6	1.66	19.0	78	89	21.1	87	1.66
7	1.64	11.4	46	0	11.3	45	1.64
8	1.66	11.8	49	382	20.0	82	1.65
9	1.69	17.1	72	251	22.0	95	1.66

Water uptake: measured by the automatic volume change.

Final ρ_d : Calculated according to the final dry density distribution throughout the sample (supposing constant cell volume).

Ex5: Water from the thermostatic bath entered through the heater hole.

TABLE III
SUCTION CONTROLLED OEDOMETRIC TESTS. MERCURY POROSIMETRY DATA.

Sample	e ₁	e ₂	% total	average ϕ (μ)	% large	Mode large (μ)	% medium	Mode medium (μ)	% small	Mode small Å	Unif. coef.
EDS1_1	0.793	0.255	32	0.01	21	5.3	28	0.3	50	63	83
EDS2_1	0.793	0.270	34	0.01	19	5.4	27	0.3	47	63	176
EDS3_1	0.737	0.256	34	0.01	41	26.8	14	0.3	45	63	
EDS5_1	0.771	0.205	27	0.01	23	18.3	27	0.3	49	63	84
EDN1_1	1.090	0.169	15	0.009	12	6.13	15	0.3	73	63	3
EDN2_1	1.138	0.167	14	0.0085	8	11.4	15	0.3	77	63	2
EDN3_1	1.090	0.208	19	0.01	23	4.8	29	0.3	48	63	65
EDN4_1	1.155	0.189	16	0.01	35	20.2	8	0.2	56	63	384
EDN5_1	1.090	0.246	22	0.01	34	34.3	10	0.15	56	63	24
EDS1_2	0.771	0.244	32	0.01	44	10	21	0.32	35	50	765
EDS2_2	0.737	0.238	32	0.02	35	6	28	0.32	37	63	137
EDS3_2	0.623	0.182	29	0.01	19	7	28	0.26	53	56	36
EDS4_2	0.727	0.303	42	0.02	39	12	24	0.32	36	63	325
EDS5_2	0.716	0.231	32	0.02	35	13	24	0.32	40	63	180
EDN1_2	0.723	0.191	26	0.01	29	13	18	0.32	53	63	65
EDN2_2	1.029	0.247	24	0.01	35	9.2	16	0.32	49	63	152
EDN3_2	0.616	0.206	33	0.01	31	12	21	0.32	48	63	84
EDN4_2	0.727	0.209	29	0.01	32	16	20	0.32	48	63	137
EDN5_2	0.695	0.185	26	0.01	27	10	21	0.32	52	63	40
NOT TESTED	0.635	0.302	48	0.02	20	5	58	0.7	21	80	84

e₁: void ratio by bulk measurement. e₂: void ratio by Hg injection. % total: percentage of total pore volume intruded by Hg. average ϕ (μ): average pore diameter. % large, medium or small: percentage of large (>2-3 μ), medium or small (<0.05 μ) pores. mode large (μ), medium (μ) or small (Å): mode of large, medium or small pores. unif. coef.: uniformity coefficient of pores ϕ_{40}/ϕ_{80}

TABLE IV
FAILURE PARAMETERS OF MONTMORILLONITE WITH DIFFERENT WATER CONTENTS AND INITIAL
 ρ_d 1.65 g/cm³ OBTAINED IN TRIAXIAL TESTS.

w (%)	Initial Sr (%)	Range σ_3	Cohesion (MPa)	Friction angle ($^\circ$)
10	41	Low (0.5-3 MPa)	0.1	33
		High (10-30 MPa)	7	8
15	61	Low	0.8	31
		High	5	6
20	81	Low	1.2	21
		High	3	2

TABLE V
FAILURE PARAMETERS OF MONTMORILLONITE WITH DIFFERENT INITIAL ρ_d
AND STABILIZED w OBTAINED IN TRIAXIAL TESTS.

Initial ρ_d (g/cm³)	Initial Sr (%)	Range σ_3	Cohesion (MPa)	Friction angle ($^\circ$)
1.60	100	Medium (3-10 MPa)	0	7
		High (10-30 MPa)	0.2	4
1.60	41 - 47	Low (0.5-3 MPa)	0.7	25
		Medium	2.8	14
		High	4.4	14
1.70	49 - 60	Low	0.8	30
		Medium	1.0	26
		High	3.5	16
1.80	53 - 59	Medium	4.3	16
		High	3.6	18
1.90	65 - 79	High	4.5	19

TABLA VI
THERMAL CONDUCTIVITY (λ) VALUES OBTAINED IN COMPACTED MONTMORILLONITE BLOCKS.

ρ_d (g/cm ³)	w (%)	λ (W/mK)	Sr (%)
1.78	0.5	0.48	2
1.55	1.3	0.42	5
1.77	9.8	0.84	48
1.60	10.2	0.73	38
1.40	10.7	0.52	30
1.75	13.5	1.07	64
1.61	14.0	0.94	54
1.40	14.6	0.65	41
1.41	18.6	0.85	53
1.58	19.1	1.08	70
1.80	18.1	1.27	92

6

FIGURES

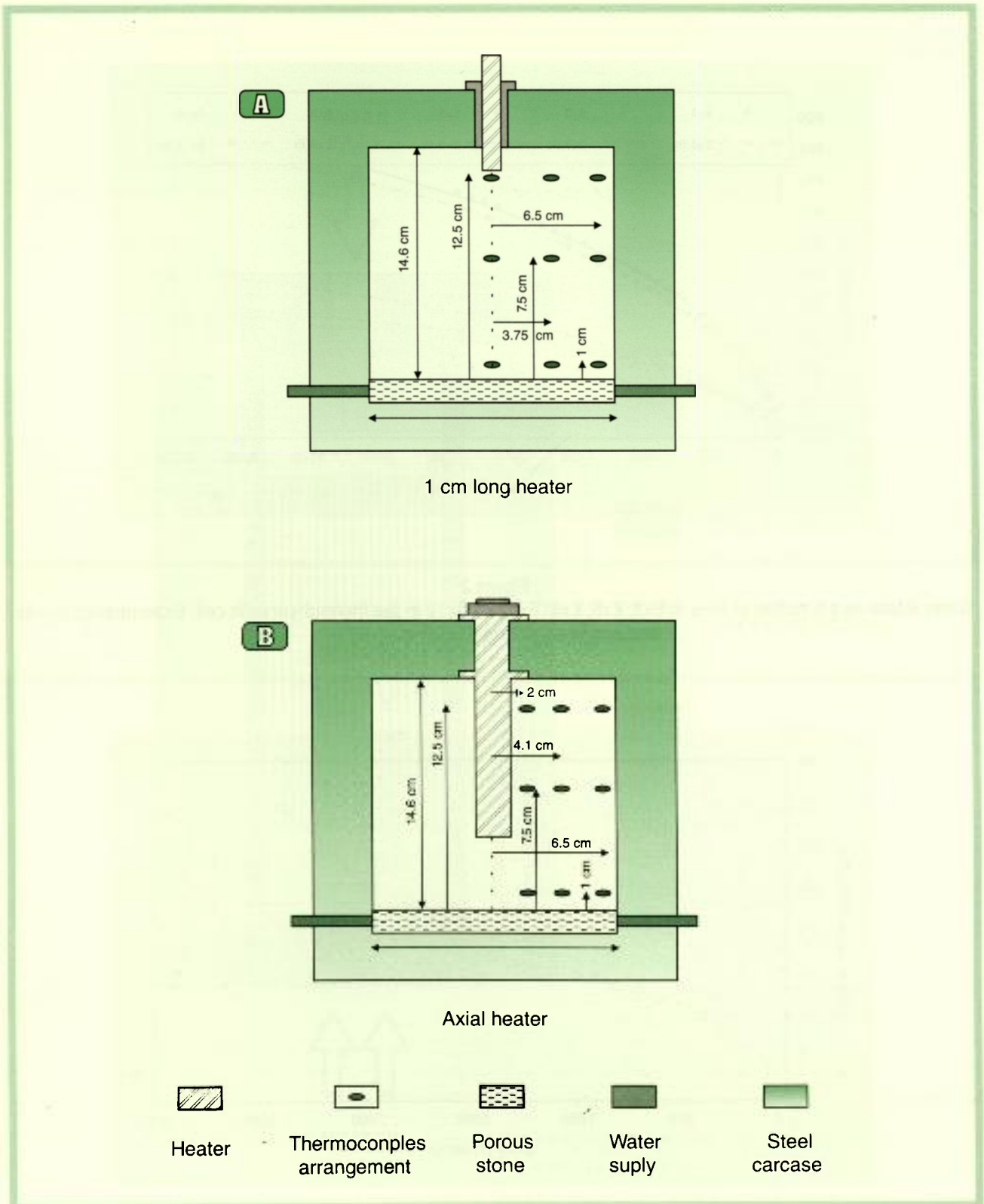


Figure 1
Schematic representation of the thermohydraulic cell with location of thermocouples.
a) 1 cm long heater, b) axial heater.

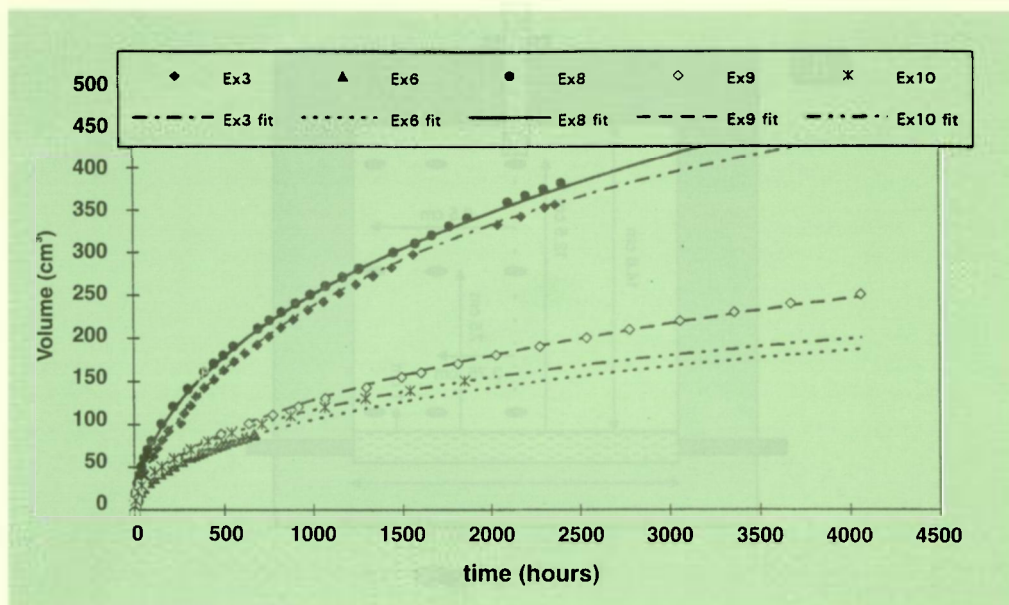


Figure 2

Water intake as a function of time in Ex3, Ex6, Ex8, Ex9 and Ex10 in the thermohydraulic cell. Experimental points and non linear fitting ($Q=A(1-\exp(-Bt^c))$)

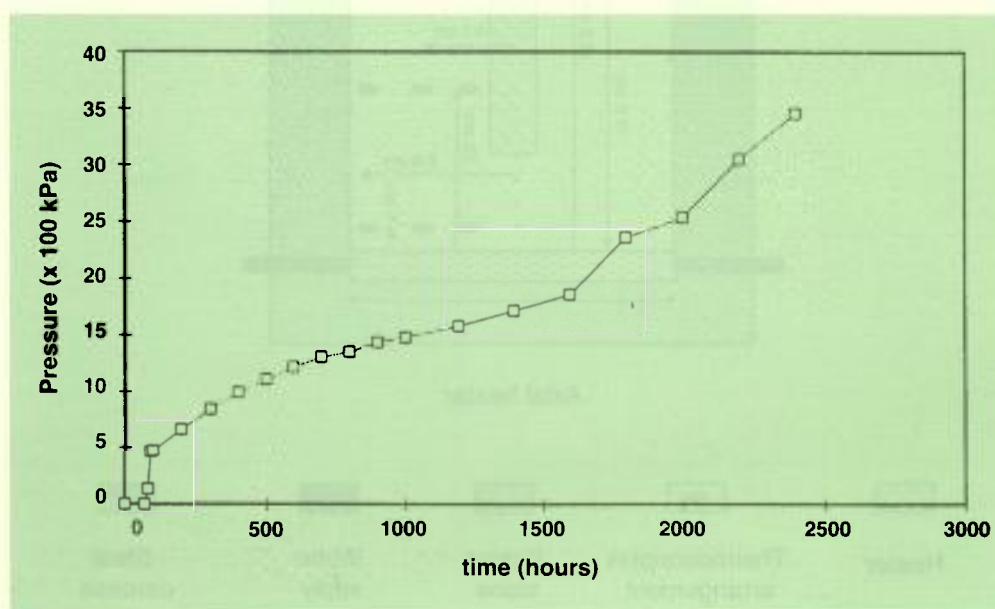


Figure 3

Pressure evolution in the cell wall at 1 cm from the bottom in Ex8.

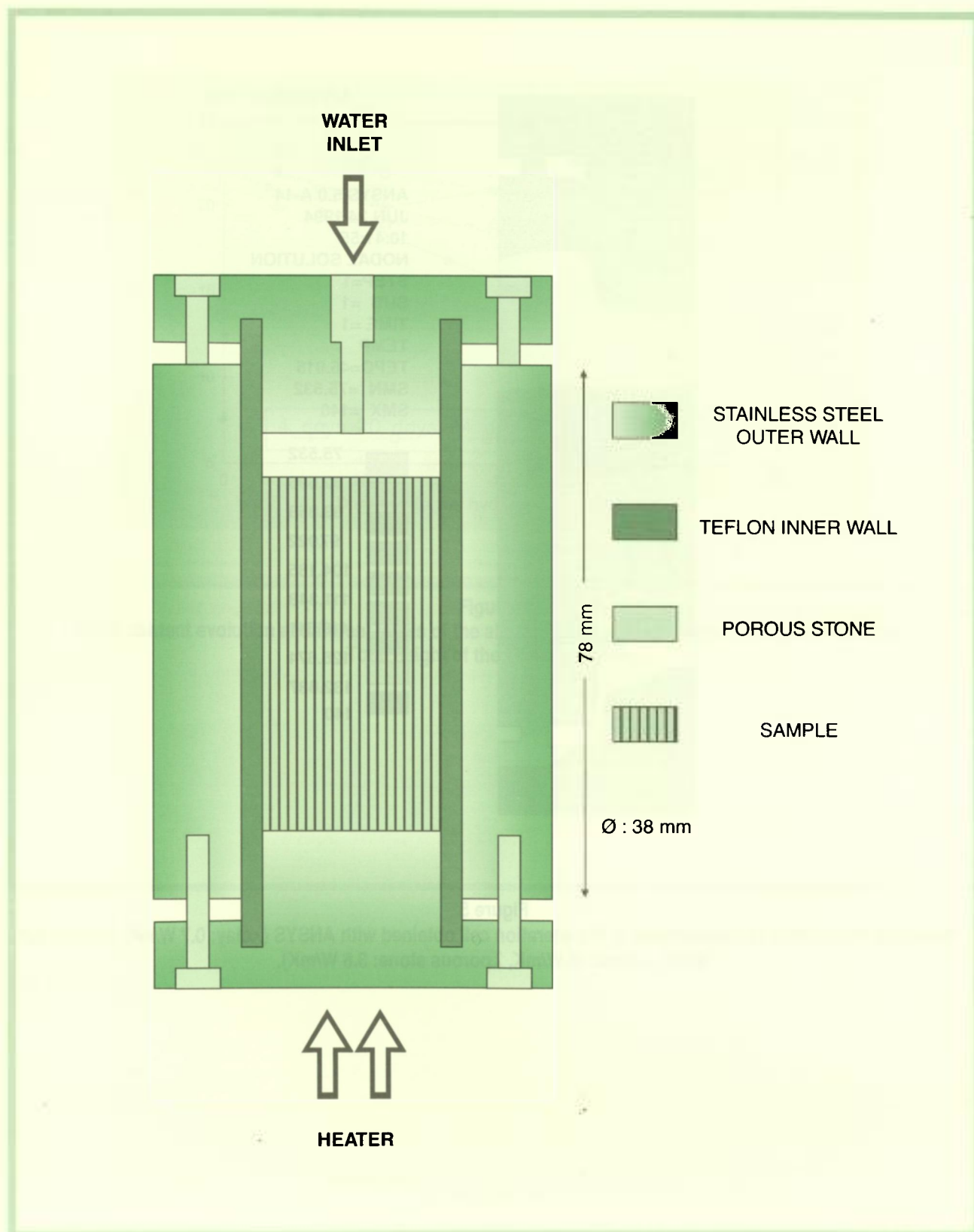


Figure 4
Schematic representation of the alteration cell.

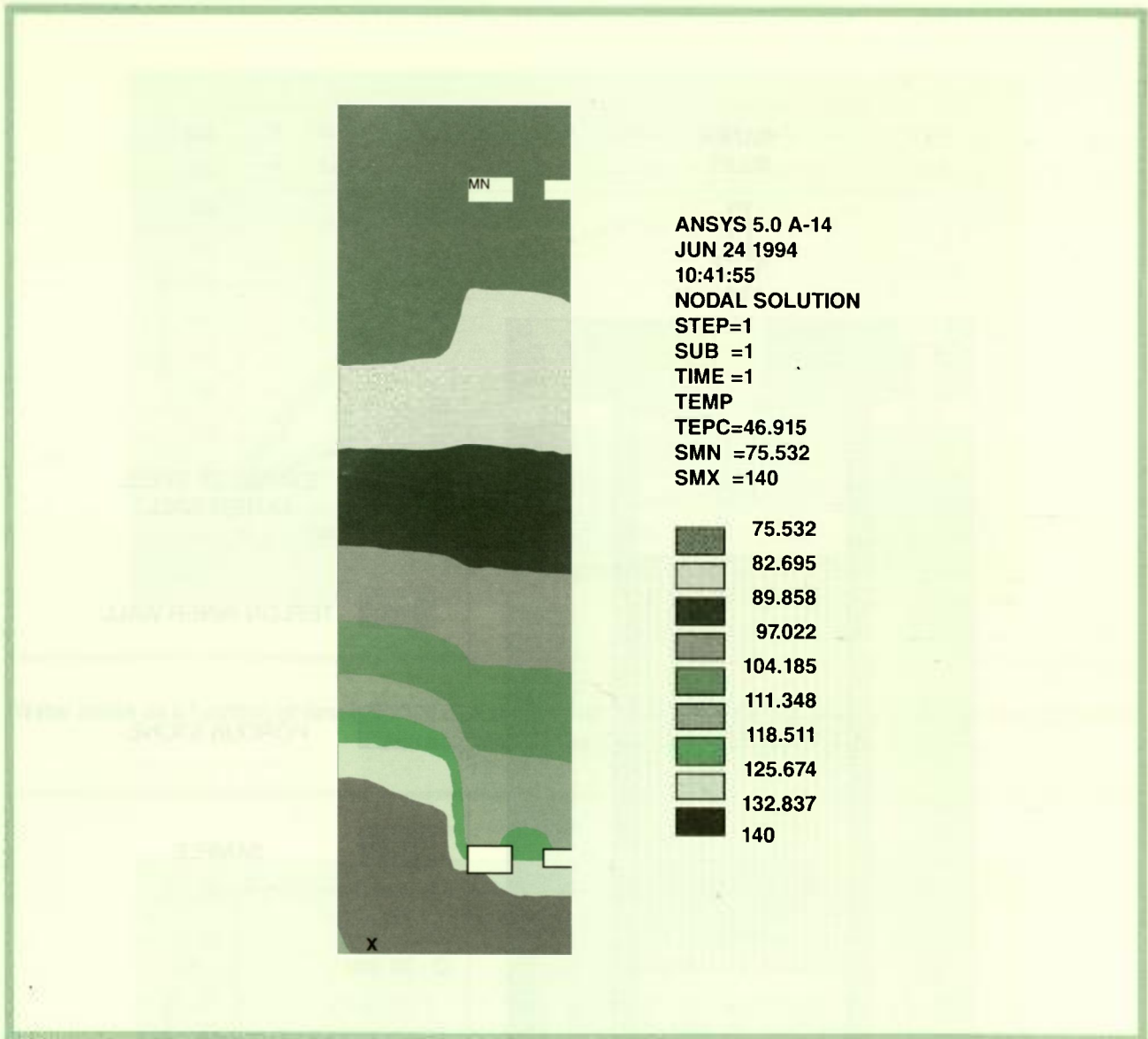


Figure 5

Theoretical distribution of temperatures in the alteration cell obtained with ANSYS (λ_{clay} : 0.7 W/mK, λ_{teflon} : 0.3 W/mK, λ_{steel} : 15 W/mK, $\lambda_{\text{porous stone}}$: 3.6 W/mK).

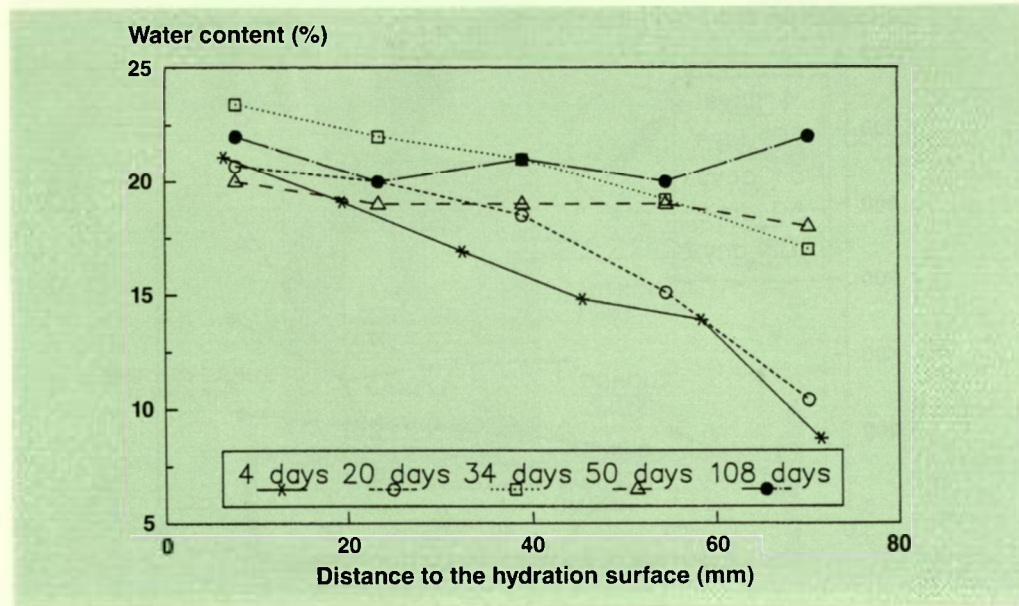


Figure 6
 Water content evolution at different levels of the alteration cell in experiments of different duration.
 Total height of the sample: 78 mm.

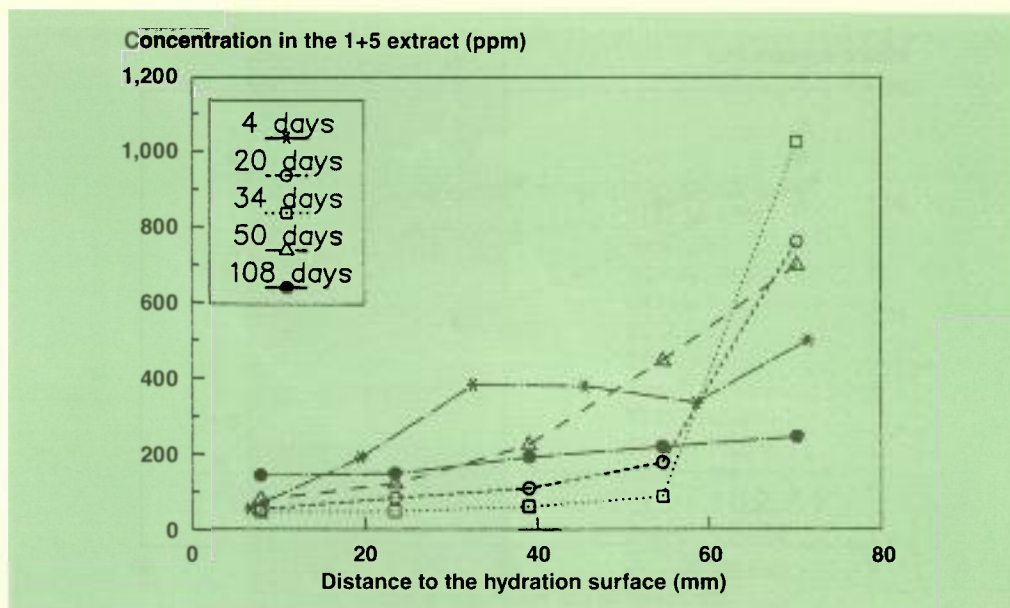


Figure 7

Final chloride concentration (ppm) in the 1+5 extract at different levels of the alteration cell in experiments of different duration. Total height of the sample: 78 mm.

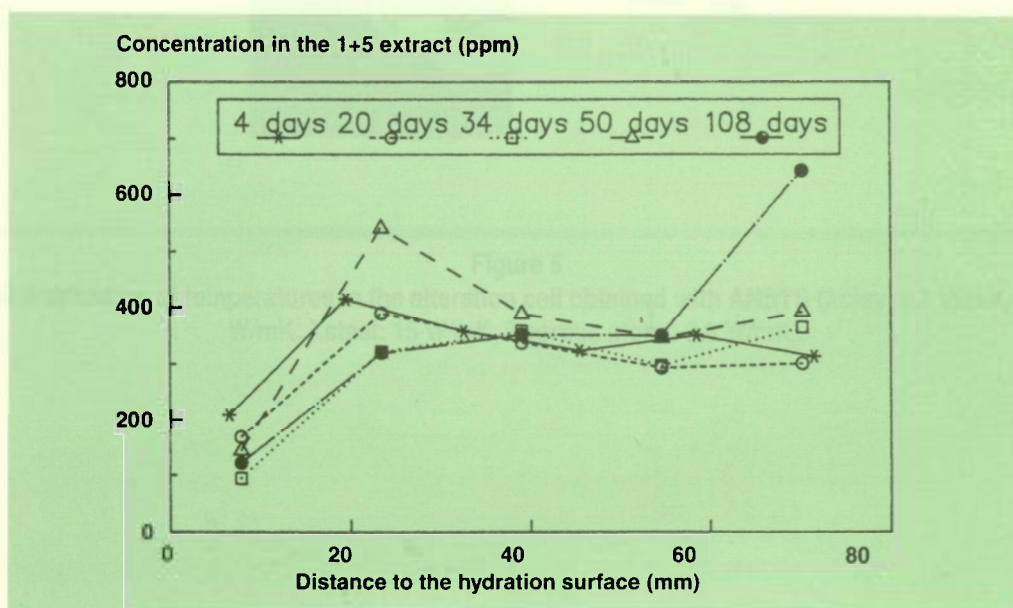


Figure 8

Final sulphate concentration (ppm) in the 1+5 extract at different levels of the alteration cell in experiments of different duration. Total height of the sample: 78 mm.

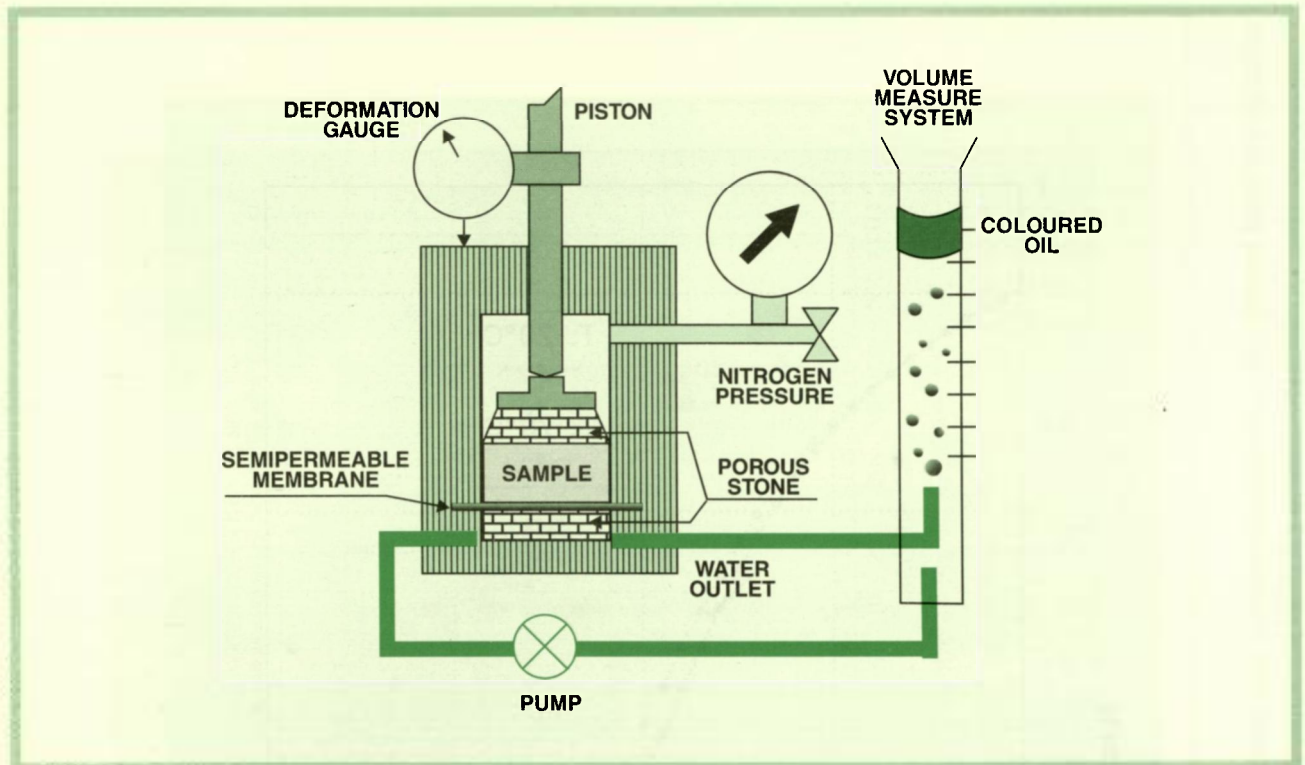


Figure 9
Schematic representation of the suction controlled oedometer cell with nitrogen pressure.

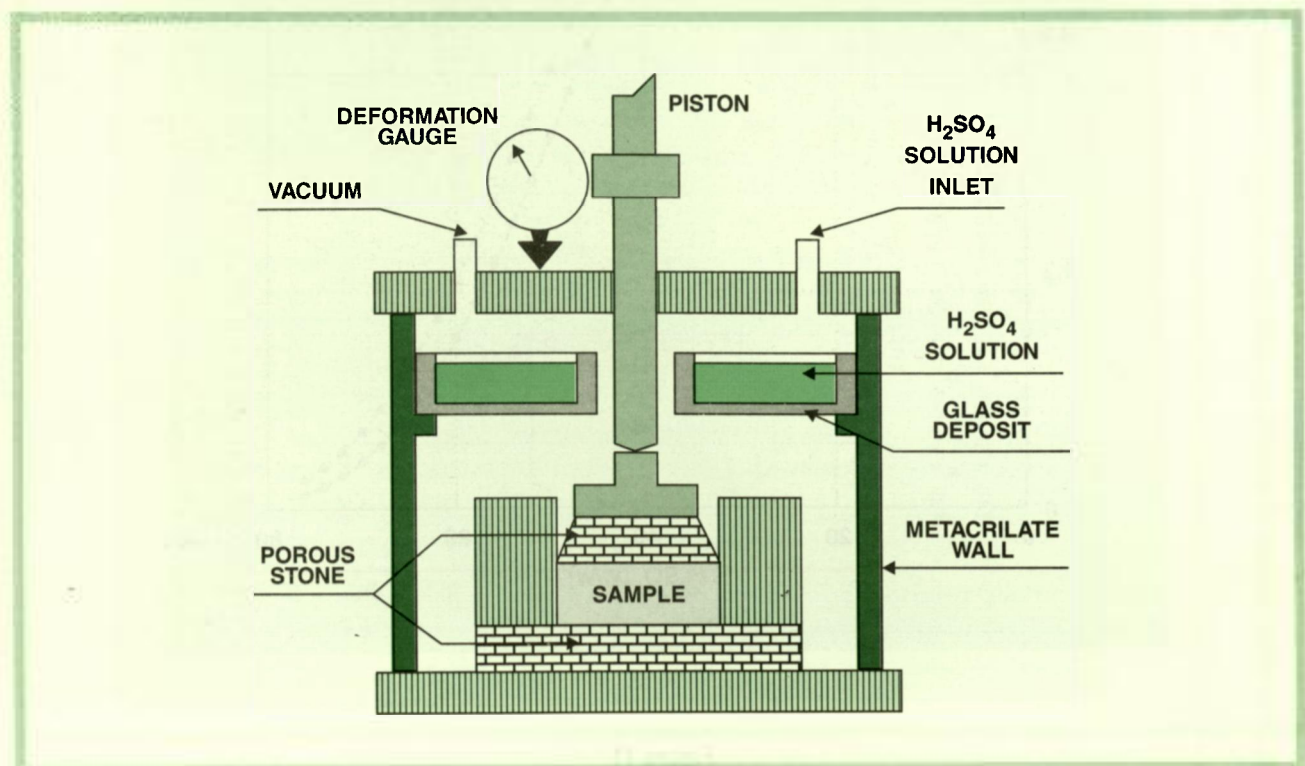


Figure 10
Schematic representation of the suction controlled oedometer cell with sulfuric acid solutions.

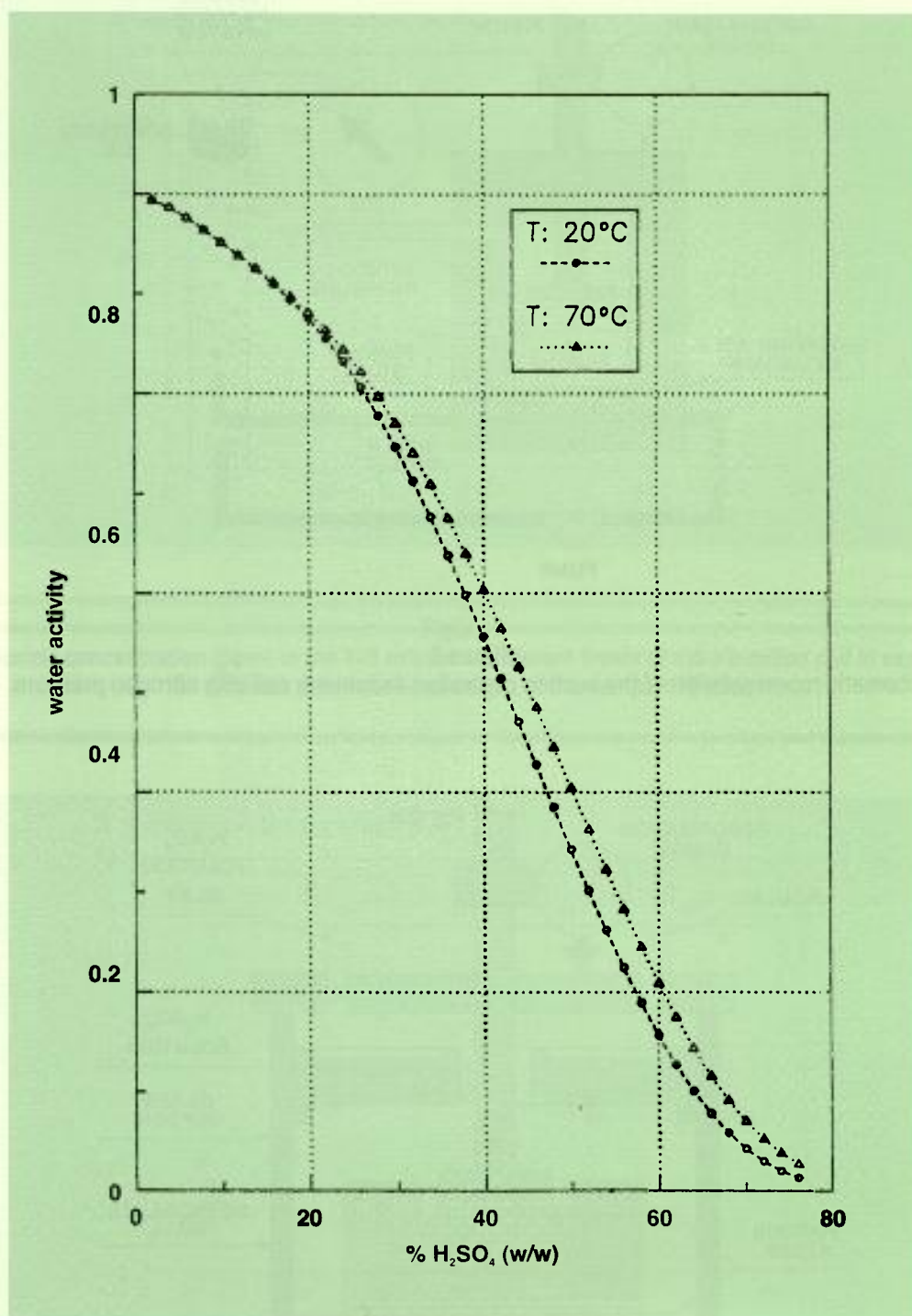
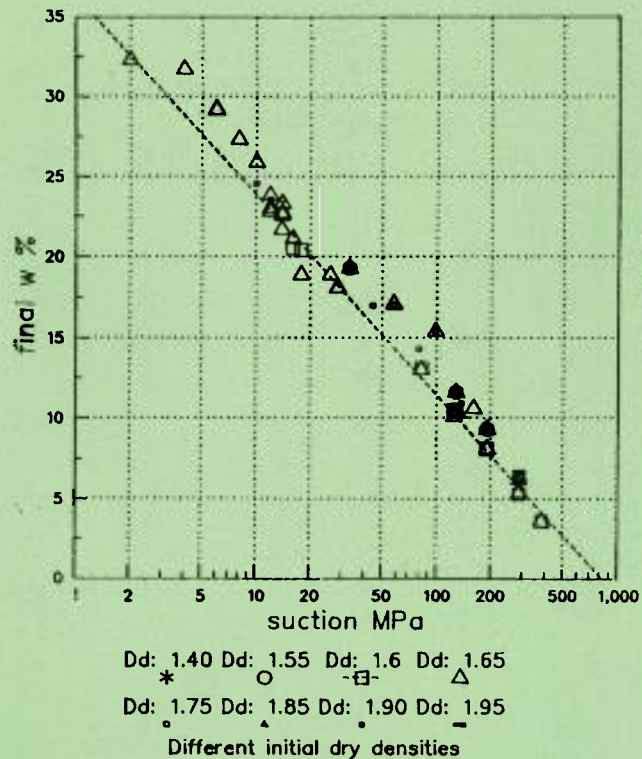


Figure 11
Relation between weight percentage of H_2SO_4 and water activity of the solution at 20°C and 70°C
(data from Gmitro & Vermeulen 1964).

a) EQUILIBRIUM WATER CONTENT vs SUCTION
Montmorillonite. Initial w: 11%



b) FINAL WATER CONTENT vs SUCTION
Montmorillonite. Initial dry density 1.65 g/cm³

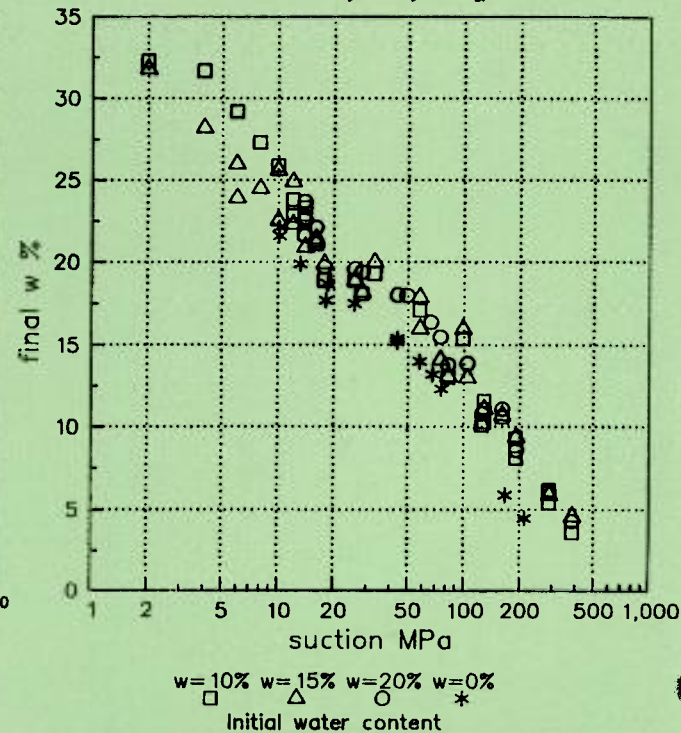
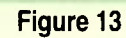


Figure 12

Equilibrium water content vs suction for montmorillonite in membrane cells and sulfuric acid solution desiccators. a) for different initial dry densities and stabilized water content, b) for different initial water contents and initial dry density 1.65 g/cm³.



Void ratio at the end of each step in the first set of suction controlled oedometer tests performed in nitrogen cells. Montmorillonite, initial $\rho_d = 1.60 \text{ g/cm}^3$ and $w = 11\%$. a) dessication-hydration cycles, b) loading-unloading cycles.

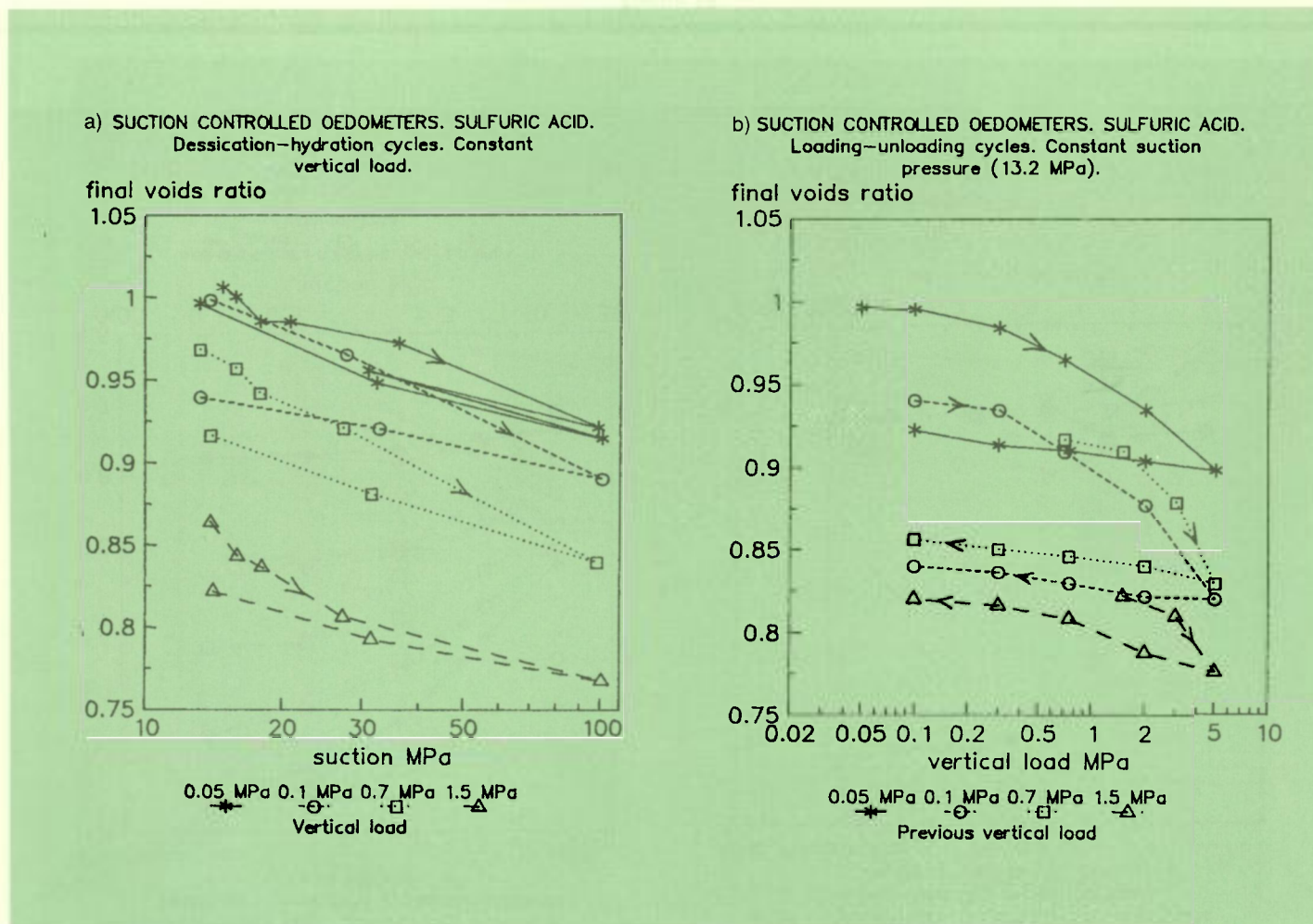


Figure 14

Void ratio at the end of each step in the first set of suction controlled oedometer tests performed in sulfuric acid solutions cells. Montmorillonite, initial $\rho_d = 1.60 \text{ g/cm}^3$ and $w = 11\%$. a) dessication-hydration cycles, b) loading-unloading cycles.

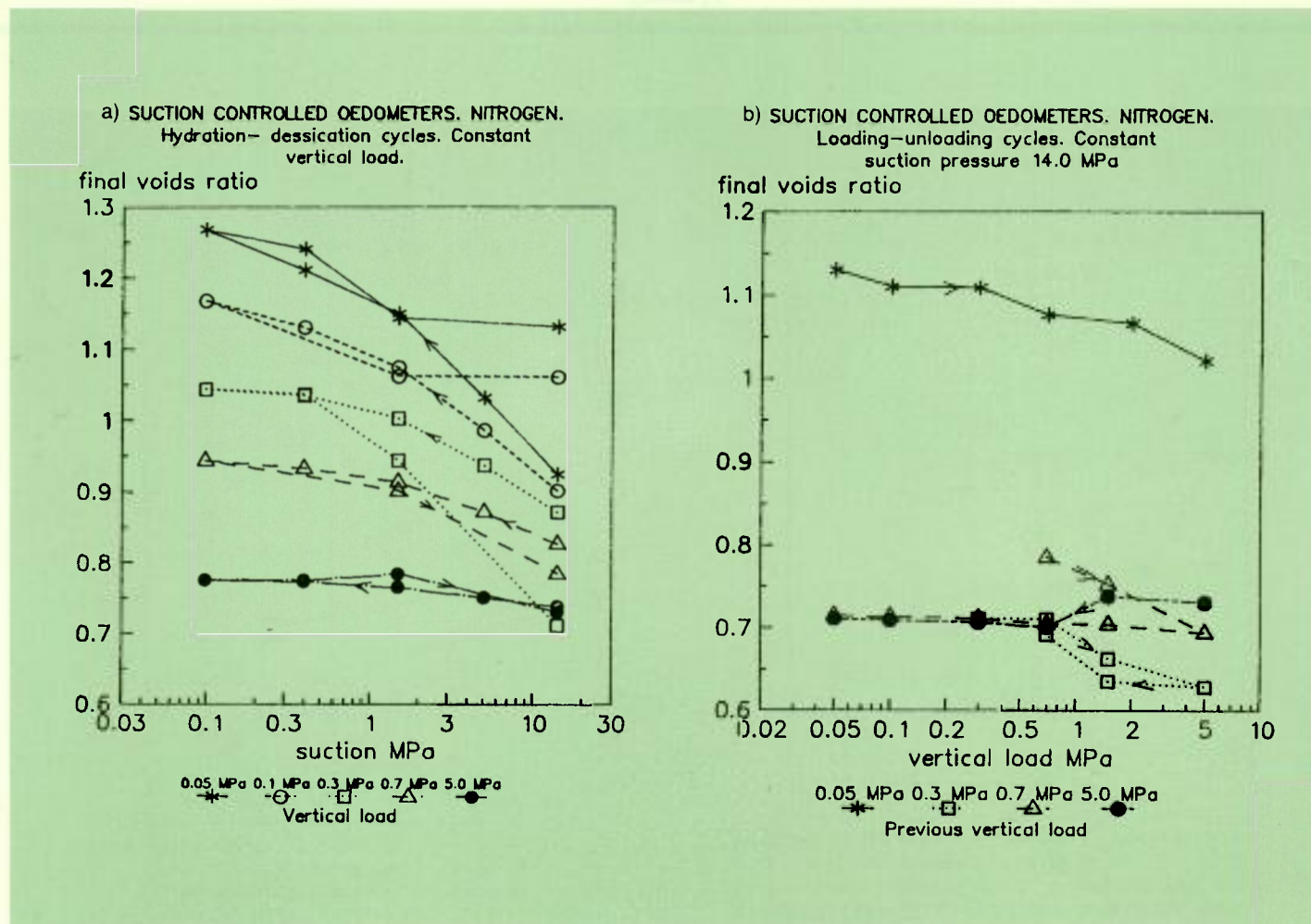


Figure 15

Void ratio at the end of each step in the second set of suction controlled oedometer tests performed in nitrogen cells. Montmorillonite, initial $\rho_d = 1.60 \text{ g/cm}^3$ and $w = 11\%$. a) hydration-dessication cycles, b) loading-unloading cycles.

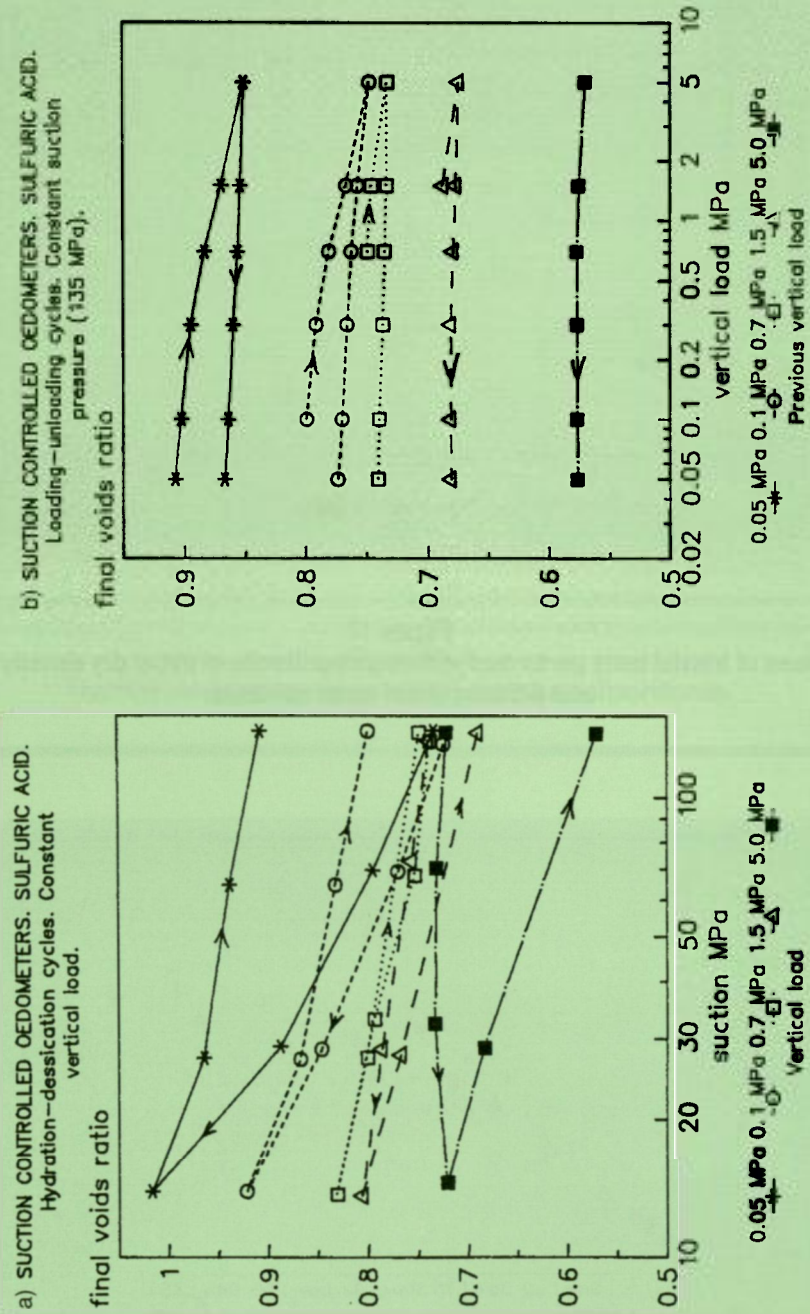


Figure 16

Void ratio at the end of each step in the second set of suction controlled oedometer tests performed in sulfuric acid solutions cells. Montmorillonite, initial $p_d = 1.60 \text{ g/cm}^3$ and $w = 11\%$. a) hydration-dessication cycles, b) loading-unloading cycles.

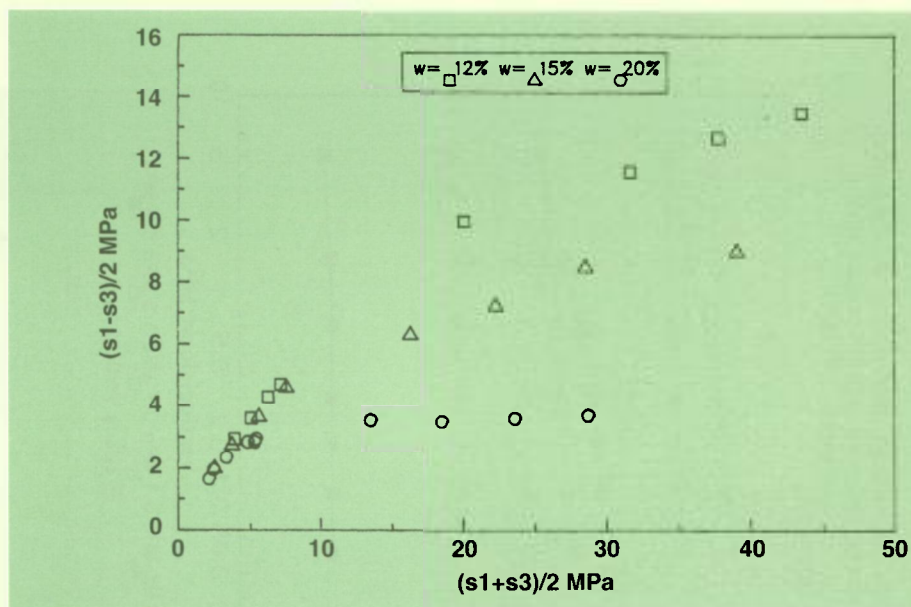


Figure 17
Failure values of triaxial tests performed with montmorillonite of initial dry density 1.65 g/cm^3 and different initial water contents.

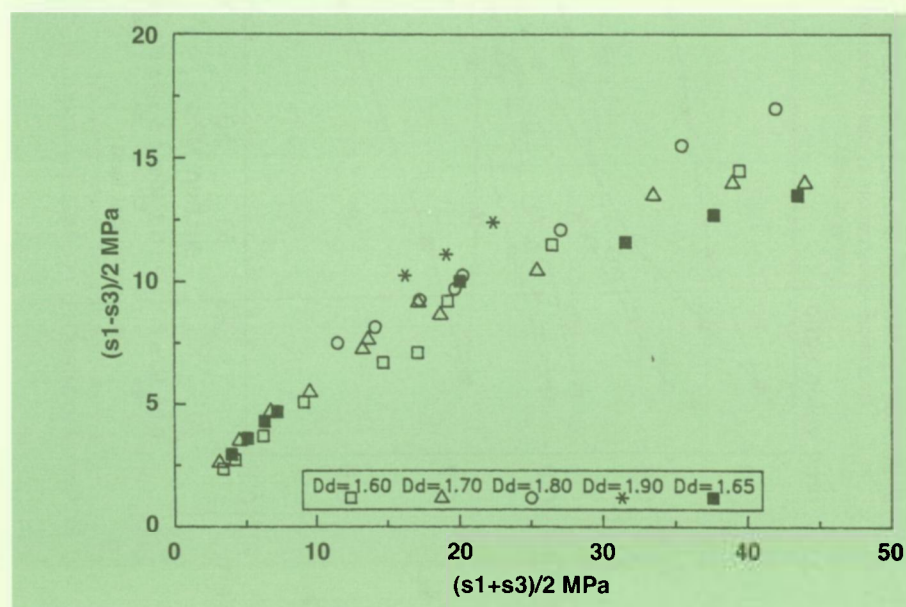


Figure 18
Failure values of triaxial tests performed with montmorillonite of initial water content around 11% and different initial dry densities (g/cm^3).

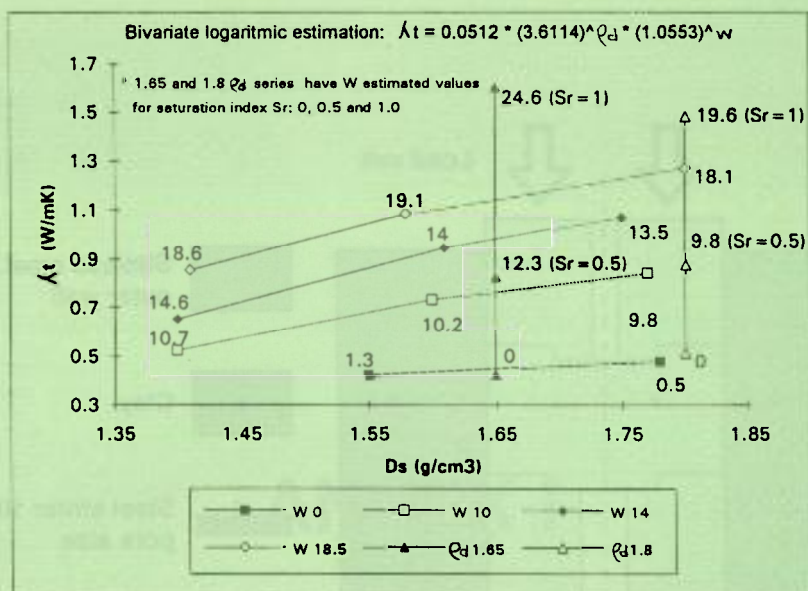


Figure 19
Thermal conductivity values of compacted montmorillonite.

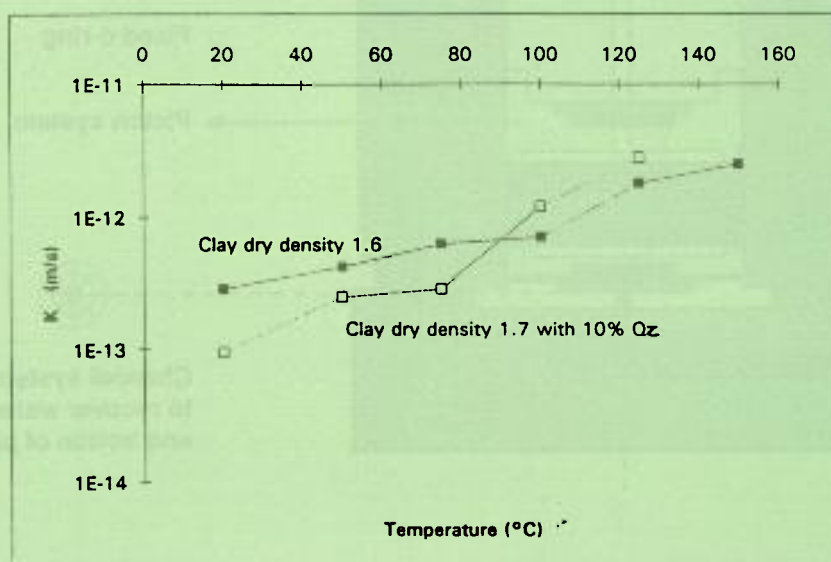


Figure 20
Hydraulic conductivity measures at different temperatures for compacted montmorillonite.

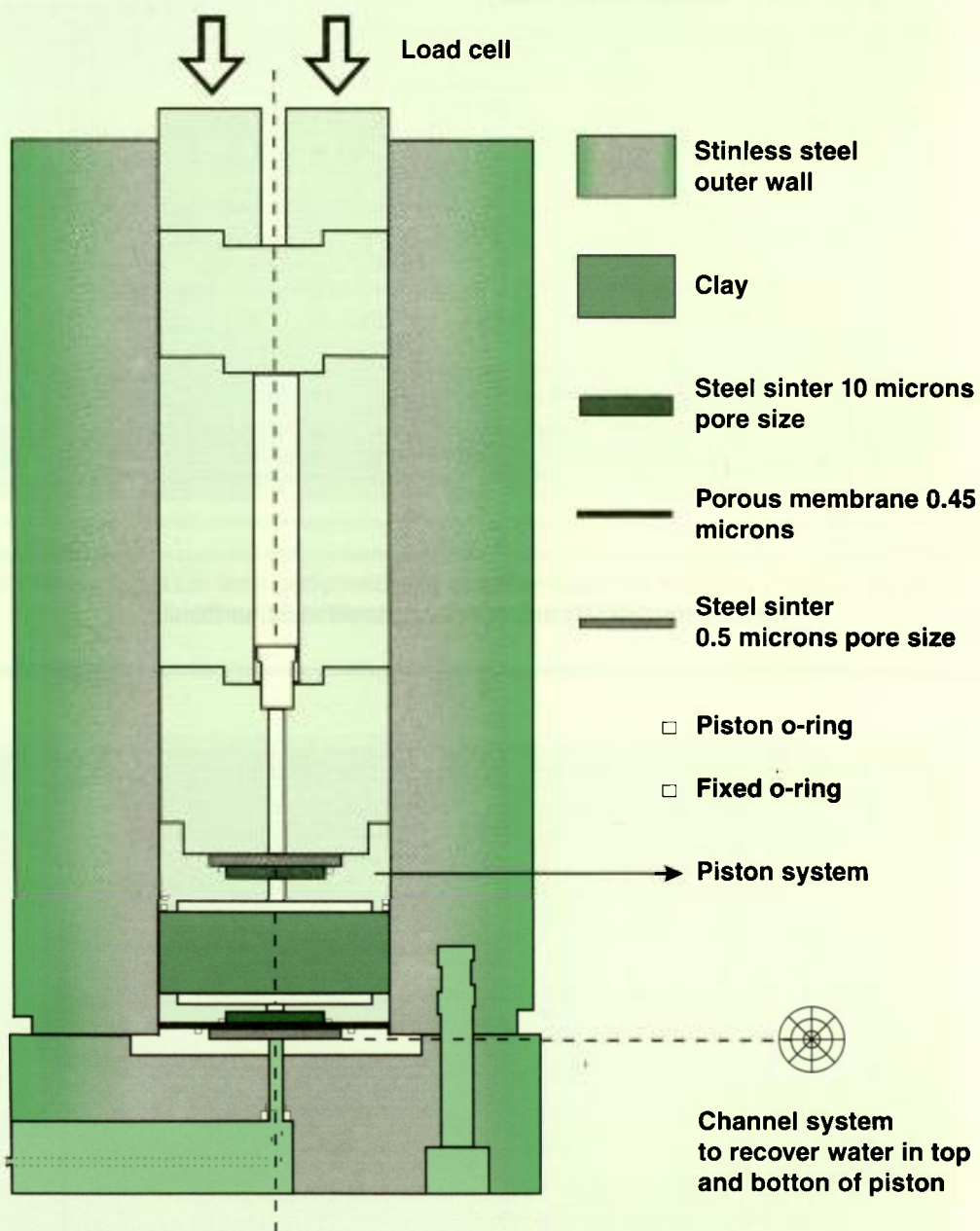


Figure 21
Schematic representation of the squeezing apparatus.

ANNEX I

THERMOHYDRAULIC CELL



Figure 11

Schematic representation of the thermohydraulic cell.

THERMOHYDRAULIC CELL
Position of thermocouples with the 1 cm long heater.

#	1	2	3	4	5	6	7	8	9
x	0.00	3.75	6.50	0.00	3.75	6.50	0.00	3.75	6.50
y	12.50	7.50	1.00	1.00	12.50	7.50	7.50	1.00	12.50

THERMOHYDRAULIC CELL
Position of thermocouples with the axial heater. #10, 11 & 12 corresponding to heater surface.

#	1	2	3	4	5	6	7	8	9	10	11	12
x	2.00	4.10	6.50	2.00	4.10	6.50	2.00	4.10	6.50	1.00	1.00	1.00
y	12.50	7.50	1.00	1.00	12.50	7.50	7.50	1.00	12.50	7.00	9.50	12.00

THERMOHYDRAULIC CELL
Position of pressure transducers.

#	1	2	3
x	7.5	7.5	7.5
y	1.25	7.75	12.75

(0,0): bottom and center of clay

THERMOHYDRAULIC CELL			
Experiment nº:		3	
Material:		Montmorillonite clay S-2	
Initial w:	10.1%	Initial pd:	1.65 g/cm ³
Sample manufacturing date:			
Heater:		1 cm long	
nº cycles:	4	Hydratation:	In cycle #4
Cycle nº: 1			
Heater power:		37 w	
Heater T °C:		No	
Lab. T °C:		Bath 30 °C	
Start:		18-5-92 0 h	
End:		21-5-92 72 h	
Total heating time (hours):		72 h	
Cooling time (hours):		96 h	
Remarks: Not recorded			
Cycle nº: 2			
Heater power:		37 w	
Heater T °C:		No	
Lab. T °C:		Bath 30 °C	
Start:		25-5-92 168 h	
End:		28-5-92 240 h	
Total heating time (hours):		72 h	
Cooling time (hours):		96 h	
Remarks: Not recorded			
Cycle nº: 3			
Heater power:		37 w	
Heater T °C:		No	
Lab. T °C:		Bath 30 °C	
Start:		1-6-92 336 h	
End:		10-6-92 1104 h	
Total heating time (hours):		240 h	
Cooling time (hours):		528 h	
Remarks: Not recorded			

Cycle n°:		4
Heater power:	37 w	Heater T °C: 100
Lab. T °C:		Bath 30 °C No
Start:	2-7-92 19:49 1104 h	End: 13-10-92 8:16 3579.1 h
Total heating time (hours):	2475.1 h	Cooling time (hours):
Remarks:		Only registered until 1539.8 h

Total duration of experiment: 3579.1 h

Total heating time: 2859.1 h

Total hydration time: 2475.1 h

Water uptake: 357 cm³

Final w: 19.8%

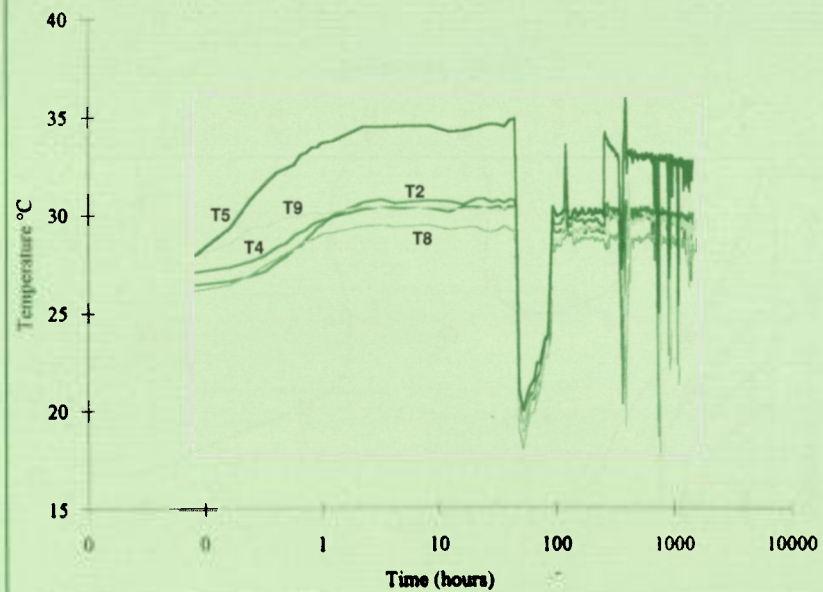
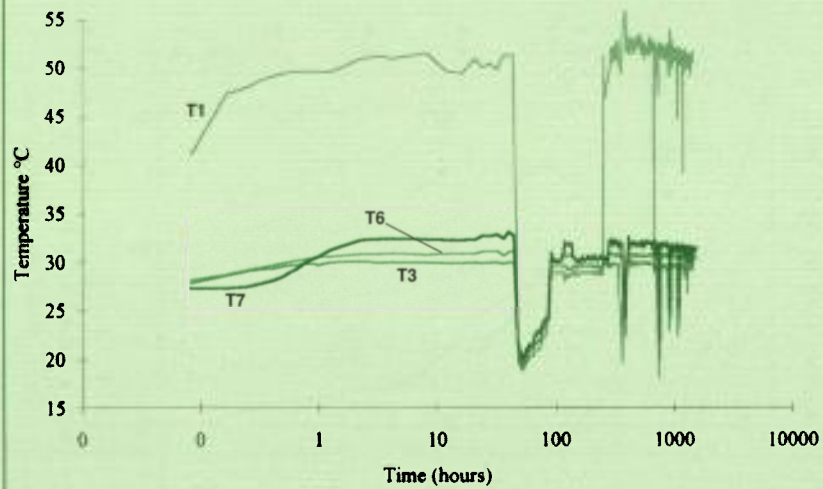
THERMOHYDRAULIC CELL. EX3 STEADY STATE TEMPERATURES-THERMOCOUPLES		
Thermocouple	T ₁ (°C)	T ₂ (°C)
1	50	50
2	31	30
3	30	30
4	30	29
5	35	32
6	31	30
7	33	31
8	29	28
9	30	29
Heater	100?	100?

T₁: 3/7/92 20:00, 1128.2 h, 24.2 h of cycle 4 (hydration 10 bar, no bath). Tamb: 24°C.

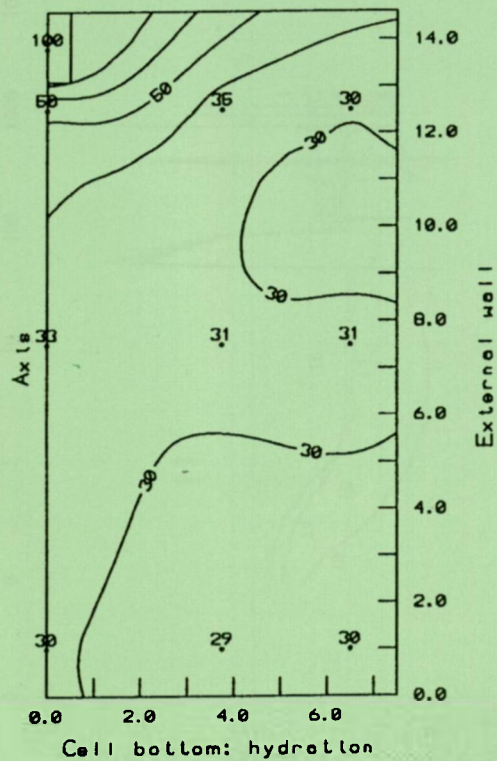
T₂: 29/8/92 20:14, 2510.3 h, 1406.3 h of cycle 4 (hydration 10 bar, no bath), Tamb: 26°C.

THERMOHYDRAULIC CELL. EX3 FINAL WATER CONTENT		
x cm	y cm	Water content %
0.0	1.0	27.0
0.0	3.0	23.1
0.0	5.0	20.6
0.0	8.0	19.2
0.0	11.0	18.0
0.0	13.0	2.7
3.0	1.0	27.2
3.0	3.0	23.3
3.0	5.0	23.3
3.0	8.0	19.4
3.0	11.0	17.9
3.0	13.5	8.9
3.0	1.0	26.9
6.0	3.0	23.6
6.0	5.0	21.1
6.0	8.0	19.4
6.0	11.0	18.3
6.0	13.5	14.0

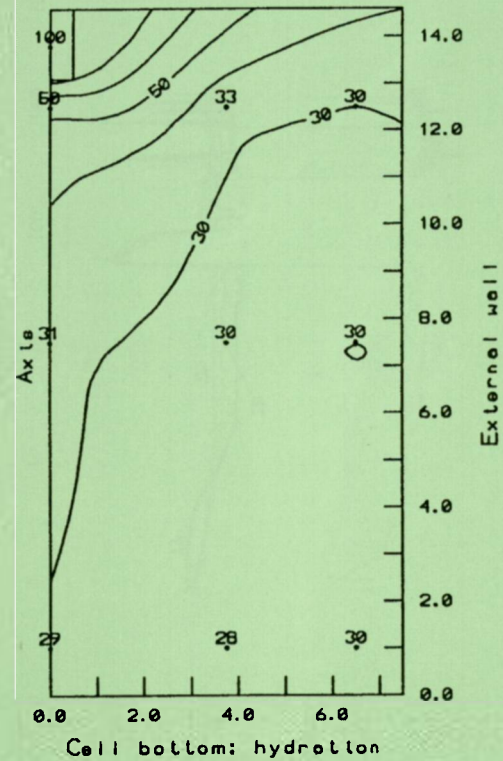
THERMOHYDRAULIC CELL. EX3. 1 cm long heater.
Hydration in cycle 4. Initial w: 10.1%, dry density: 1.65
g/cm³

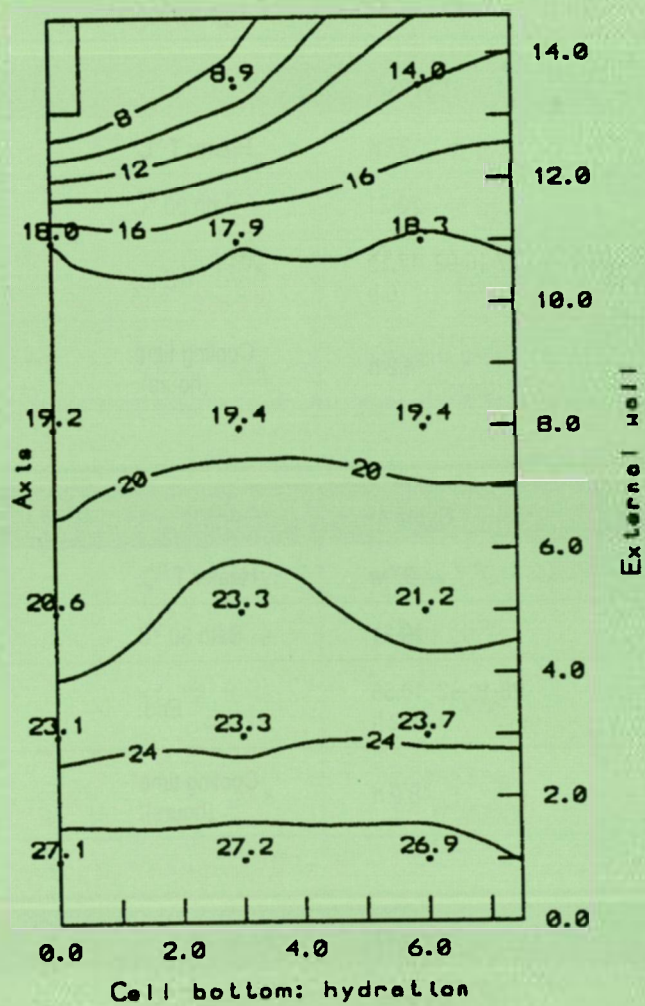


THERMOHYDRAULIC CELL, EX3, T1.



THERMOHYDRAULIC CELL, EX3, T2.



THERMOHYDRAULIC CELL. EX3. FINAL μ %

THERMOHYDRAULIC CELL			
Experiment n°:		4	
Material:		Montmorillonite clay S-2	
Initial w:	12.4%	Initial pd:	1.62 g/cm ³
Sample manufacturing date:		15-10-92	
Heater:		1 cm long	
n° cycles:	10	Hydratation:	No
Cycle n°:		1	
Heater power:	37 w	Heater T °C:	74
Lab. T °C:	20-21	Bath 30 °C	yes
Start:	27-10-92 17.15 0 h	End:	27-10-92 21.25 4.2 h
Total heating time (hours):	4.2 h	Cooling time (hours):	14
Remarks:			
Cycle n°:		2	
Heater power:	37 w	Heater T °C:	97
Lab. T °C:	19-21	Bath 30 °C	Yes
Start:	28-10-92 10.56 18.2 h	End:	30-10-92 11.52 67.1 h
Total heating time (hours):	48.9 h	Cooling time (hours):	70.5 h
Remarks:			
Cycle n°:		3	
Heater power:	37 w	Heater T °C:	96-93
Lab. T °C:	14-20	Bath 30 °C	yes
Start:	2-11-92 10:20 137.6 h h	End:	4-11-92 22-15 198.2 h
Total heating time (hours):	60.6 h	Cooling time (hours):	155.8 h
Remarks:		Only 6 hours of cooling recorded	

Cycle n°:		4
Heater power:	37 w	Heater T °C: 98
Lab. T °C:	19	Bath 30 °C yes
Start:	11-11-92 10:05 354.0 h	End: 11-11-92 13:00 357.0 h
Total heating time (hours):	3	Cooling time (hours): 28.2
Remarks:		

Cycle n°:		5
Heater power:	37 w	Heater T °C: 100
Lab. T °C:	20	Bath 30 °C yes
Start:	13-11-92 13:15 385.2 h	End: 13-11-92 13:32 385.5 h
Total heating time (hours):	0.3	Cooling time (hours): 21.2
Remarks:		

Cycle n°:		6
Heater power:	37 w	Heater T °C: 104
Lab. T °C:	17-19	Bath 30 °C Yes
Start:	14-11-92 10:45 406.7 h	End: 15-11-92 10:15 430.2 h
Total heating time (hours):	23.5	Cooling time (hours): 0.2
Remarks:		

Cycle n°:		7
Heater power:	37 w	Heater T °C: 120
Lab. T °C:	18	Bath 30 °C yes
Start:	15-11-92 10:25 430.4 h	End: 16-11-92 9:35 445.8 h
Total heating time (hours):	15.4	Cooling time (hours): 174.8
Remarks:		

Cycle n°:		8	
Heater power:	37 w	Heater T °C:	95
Lab. T °C:	20-22	Bath 30 °C	No
Start:	19-11-92 12:25 520.6 h	End:	20-11-92 10:05 541.3 h
Total heating time (hours):	20.7	Cooling time (hours):	72.5
Remarks:			

Cycle n°:			
Heater power:	37 w	Heater T °C:	101
Lab. T °C:	18-21	Bath 30 °C	No
Start:	23-11-92 10:35 613.8 h	End:	24-11-92 10:00 637.0 h
Total heating time (hours):	23.2	Cooling time (hours):	31
Remarks:			

Cycle n°:		10	
Heater power:	37 w	Heater T °C:	101
Lab. T °C:	19-22	Bath 30 °C	No
Start:	24-11-92 17:00 668.0 h	End:	29-11-92 12:08 784.0 h
Total heating time (hours):	115.9	Cooling time (hours):	23.6
Remarks:			

Total duration of experiment: 807.6 h

Total heating time: 315.8 h

Demoulding: 2-12-933

Final ρ_d and w: 1.62 g/cm³, 13.1%

THERMOHYDRAULIC CELL. EX4 STEADY STATE TEMPERATURES-THERMOCOUPLES						
Thermocouple	T ₁ (°C)	T ₂ (°C)	T ₃ (°C)	T ₄ (°C)	T ₅ (°C)	T ₆ (°C)
1	49	47	35	38	62	59
2	29	29	24	25	36	35
3	29	28	24	24	33	32
4	29	29	24	24	34	32
5	35	34	28	28	43	41
6	30	30	25	25	36	35
7	32	31	26	27	38	37
8	28	28	24	24	33	32
9	30	30	25	25	38	37
Heater	99	94	104	121	104	101

T₁: 29/10/92 18:40, 50.1 h, 31.9 h of cycle 2 (with bath, no hydration).

T₂: 3/11/92 15:15, 166.6 h, 29.0 h of cycle 3 (with bath, no hydration).

T₃: 14/11/92 18:00, 414.0 h, 7.2 h of cycle 6 (with bath, no hydration), Tamb: 18 °C.

T₄: 15/11/92 18:15, 437.5 h, 30.8 h of cycle 7 (with bath, no hydration).

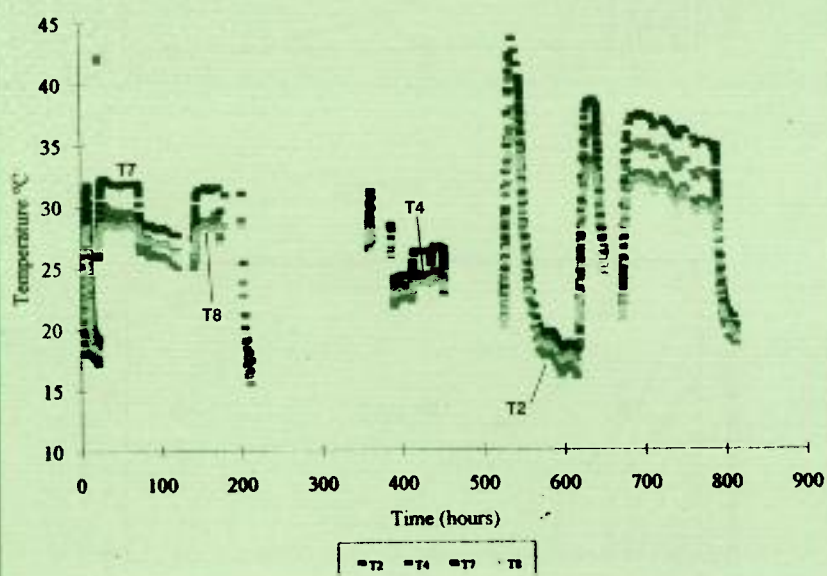
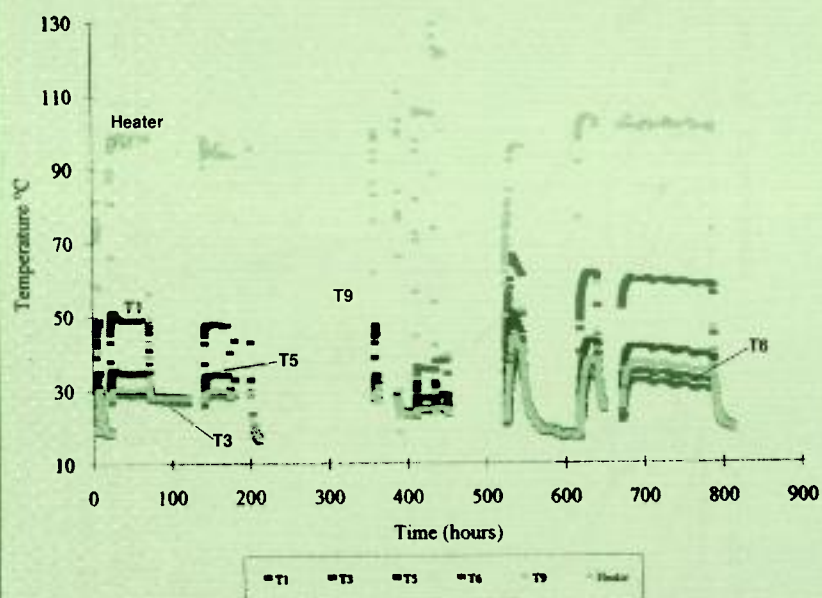
T₅: 24/11/92 3:00, 630.2 h, 16.4 h of cycle 9 (without bath, no hydration).

T₆: 26/11/92 18:00, 693.0 h, 25.0 h of cycle 10 (without bath, no hydration), Tamb: 20 °C.

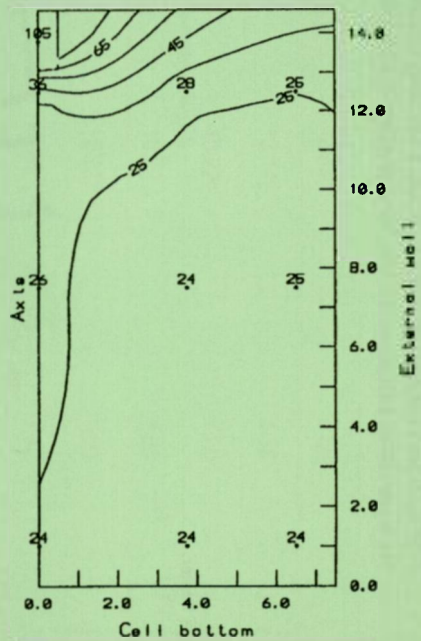
THERMOHYDRAULIC CELL. EX4
FINAL DRY DENSITY AND WATER CONTENT

x cm	y cm	Dry density g/cm³	Water content %
6	13.14	1.57	12.9
3	13.14	1.58	12.9
0	13.14	1.58	12.8
6	10.22	1.60	12.7
3	10.22	1.60	12.7
0	10.22	1.60	12.7
6	7.30	1.62	12.9
3	7.30	1.58	13.0
0	7.30	1.62	12.8
6	4.38	1.62	13.0
3	4.38	1.63	13.2
0	4.38	1.63	13.1
6	1.46	1.63	13.3
3	1.46	1.64	13.3
0	1.46	1.61	13.2

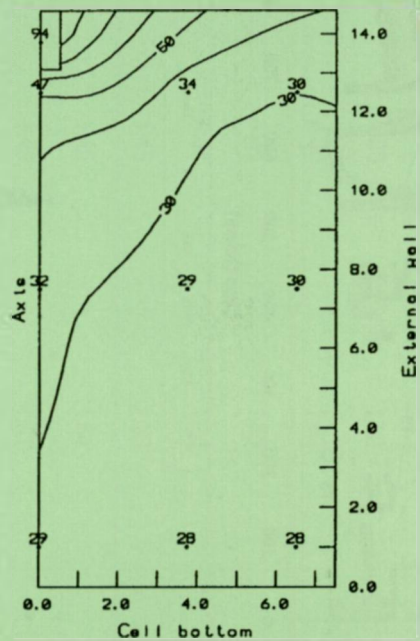
THERMOHYDRAULIC CELL. EX4. 1 cm long heater.
 No hydration. Initial w: 12.4%, dry density: 1.62 g/cm³



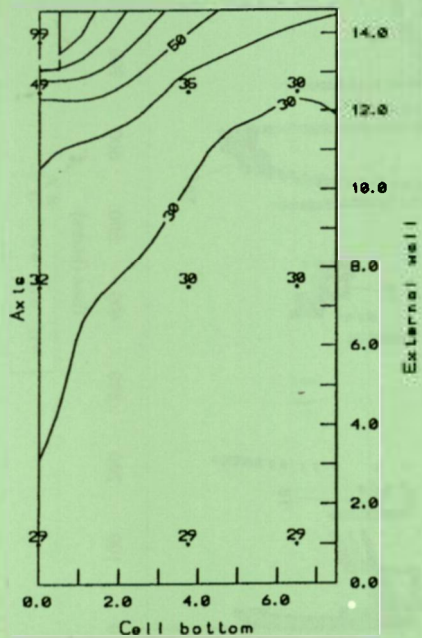
THERMOHYDRAULIC CELL. EX4. T3.

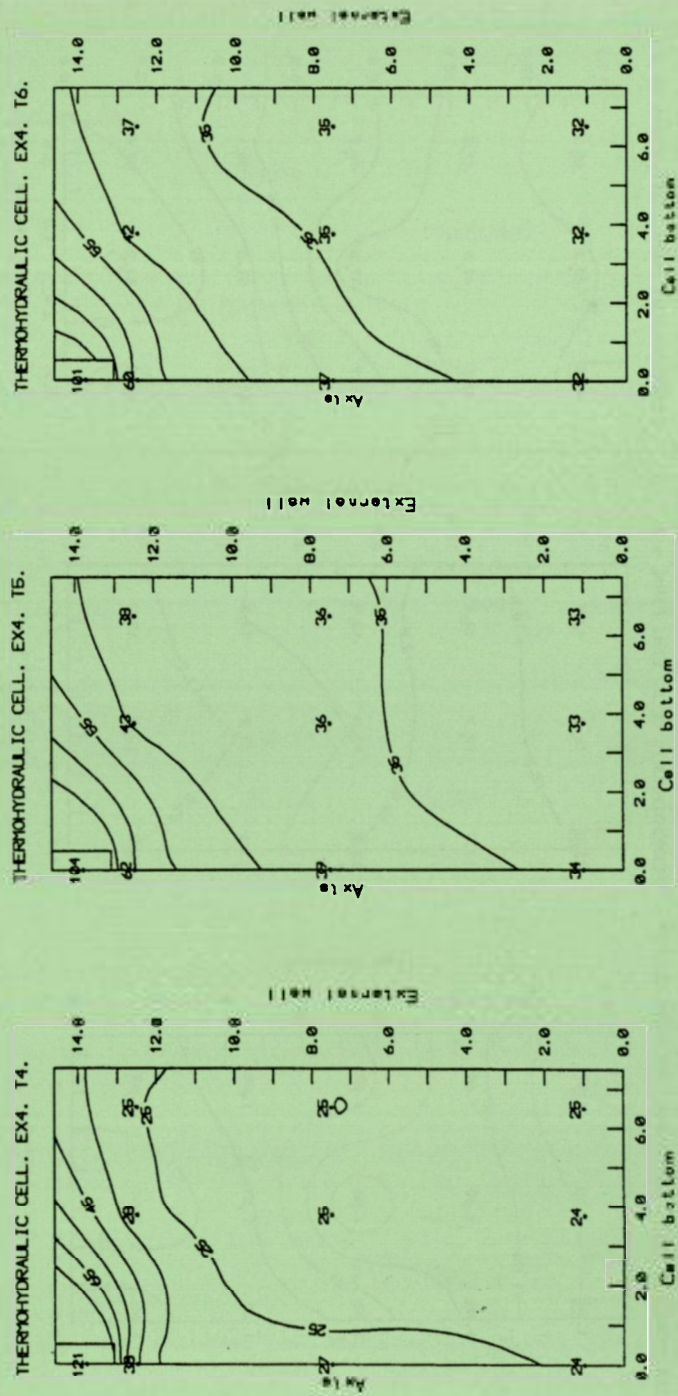


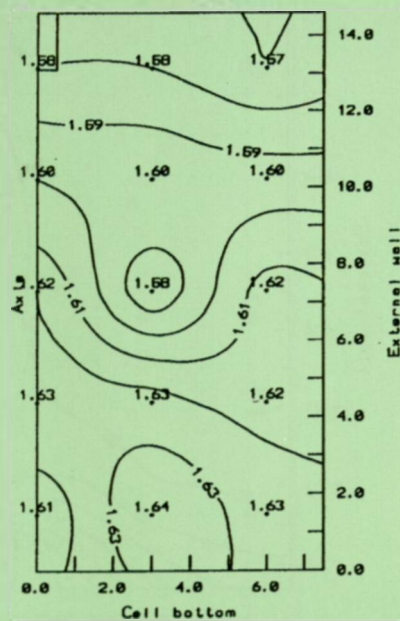
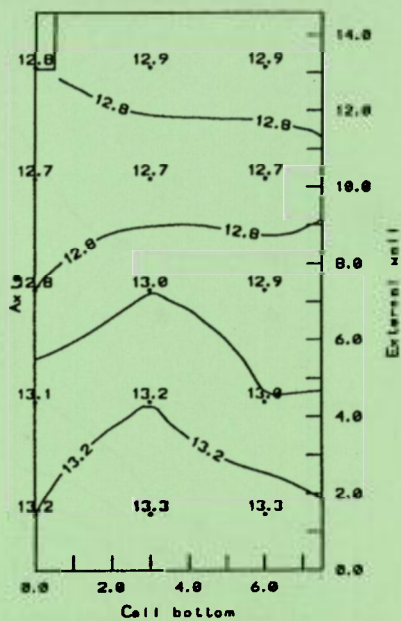
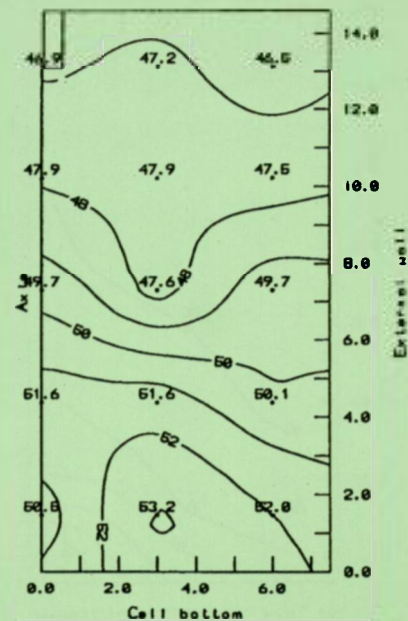
THERMOHYDRAULIC CELL. EX4. T2.



THERMOHYDRAULIC CELL. EX4. T1.





THERMOHYDRAULIC CELL. EX4. FINAL DRY DENS. g/cm^3 THERMOHYDRAULIC CELL. EX4. FINAL w %THERMOHYDRAULIC CELL. EX4. FINAL S_r %

THERMOHYDRAULIC CELL			
Experiment nº:		5	
Material:		Montmorillonite clay S-2	
Initial w:	15%	Initial pd:	1.65 g/cm ³
Sample manufacturing date:		9-12-92	
Heater:		1 cm long	
nº cycles:	4	Hydratation:	No

Cycle nº:		1	
Heater power:	37 w	Heater T °C:	99
Lab. T °C:	18-20	Bath 30 °C	No
Start:	9-12-92 17:39 0 h	End:	11-12-92 9:00 39.2 h
Total heating time (hours):	39.2	Cooling time (hours):	73
Remarks:			

Cycle nº:		2	
Heater power:	37 w	Heater T °C:	99
Lab. T °C:	20	Bath 30 °C	No
Start:	14-12-92 9:56 112.2 h	End:	15-12-92 15:17 141.2 h
Total heating time (hours):	29	Cooling time (hours):	139
Remarks:		Cooling is not completely recorded	

Cycle nº:		3	
Heater power:	37 w	Heater T °C:	94-65
Lab. T °C:		Bath 30 °C	Yes
Start:	21-12-92 10:09 28.3 h	End:	22-12-92 9:34 303.7 h
Total heating time (hours):	23.4	Cooling time (hours):	5.3
Remarks:			

Cycle n°:			
Heater power:		Heater T °C:	82-90
Lab. T °C:		Bath 30 °C	Yes
Start:	22-12-92 14:53 309.0 h	End:	14-1-93 9:36 854.7 h
Total heating time (hours):	545.7	Cooling time (hours):	6.4
Remarks:			

Total duration of experiment: 861.1 h

Total heating time: 637.3 h

Demoulding: 14-1-93

Final ρ_d and w: 1.63 g/cm³, 16.2% (water entered through the heater hole)

THERMOHYDRAULIC CELL. EX5 STEADY STATE TEMPERATURES-THERMOCOUPLES			
Thermocouple	T ₁ (°C)	T ₂ (°C)	T ₃ (°C)
1	50	38	44
2	31	25	26
3	29	25	26
4	29	25	26
5	37	30	31
6			
7	33	27	28
8	28	25	25
9	33	26	26
Heater	98	70	85

T₁: 10/12/92 18:00, 24.2 h, 24.2 h of cycle 1 (no bath, no hydration). Tamb: 18-20°C.

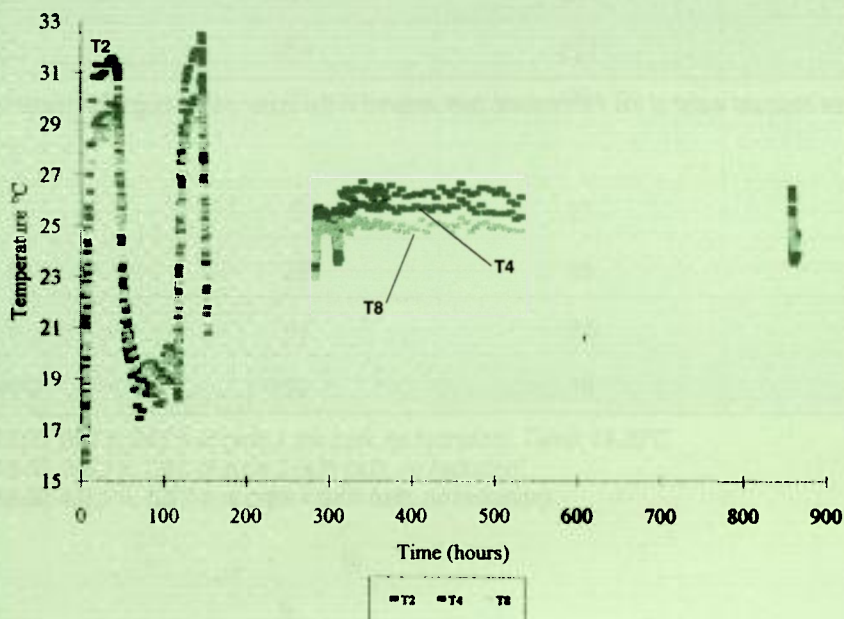
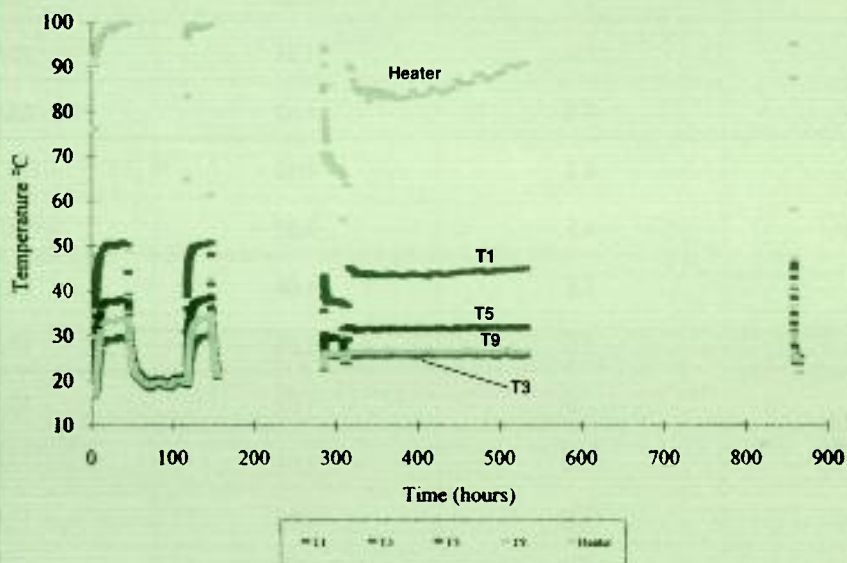
T₂: 21/12/92 18:00, 288.1 h, 7.8 h of cycle 3 (with bath, no hydration).

T₃: 27/12/92 18:00, 431.1 h, 122.1 h of cycle 4 (with bath, no hydration).

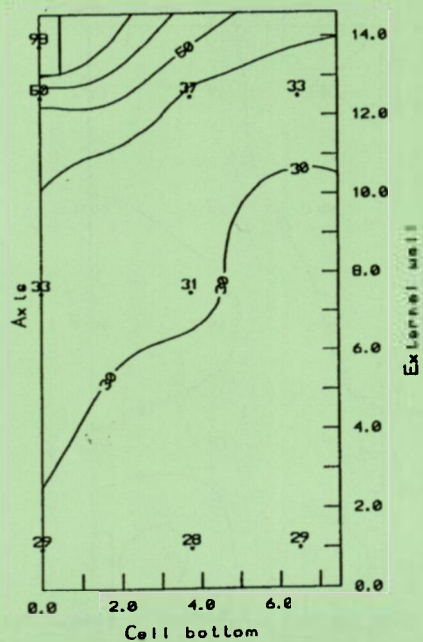
THERMOHYDRAULIC CELL. EX5 FINAL DRY DENSITY AND WATER CONTENT*			
x cm	y cm	Dry density g/cm ³	Water content %
0.0	1.5	1.63	15.1
3.0	1.5	1.63	15.3
6.0	1.5	1.61	15.5
0.0	4.5	1.63	15.8
3.0	4.5	1.63	15.7
6.0	4.5	1.62	15.7
0.0	7.5	1.64	16.1
3.0	7.5	1.63	15.2
6.0	7.5	1.62	16.1
0.0	10.5	1.63	17.0
3.0	10.5	1.63	17.0
6.0	10.5	1.62	16.8
1.9	13.5	1.61	19.0
5.4	13.5	1.63	17.4

* Anomalous values because water of the thermostatic bath entered in the upper part through the heater hole.

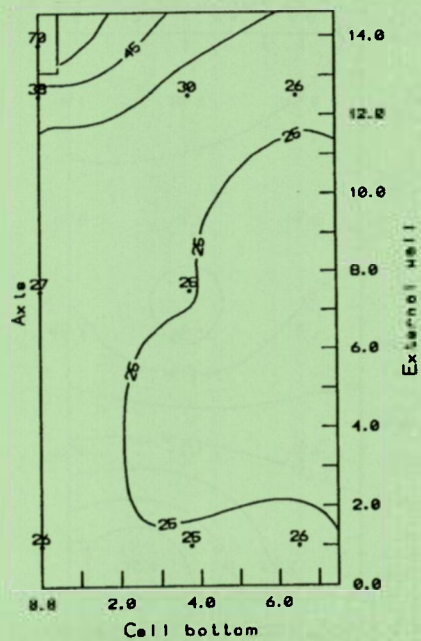
THERMOHYDRAULIC CELL. EX5. 1 cm long heater.
No hydration. Initial w: 15%, dry density: 1.65 g/cm³



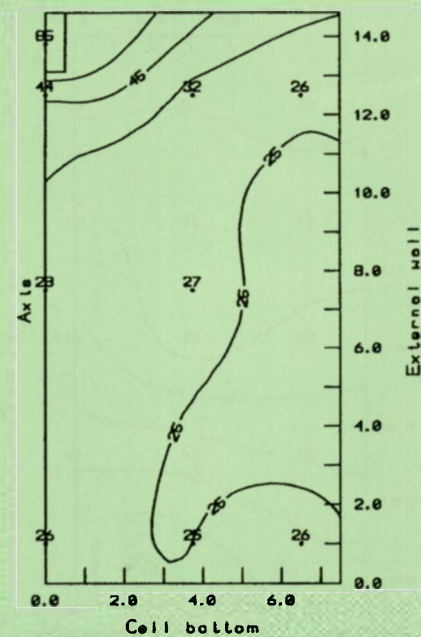
THERMOHYDRAULIC CELL, EX5. T1.

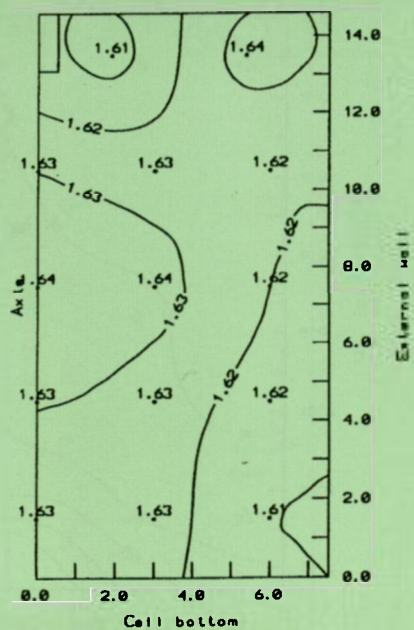


THERMOHYDRAULIC CELL, EX5. T2.

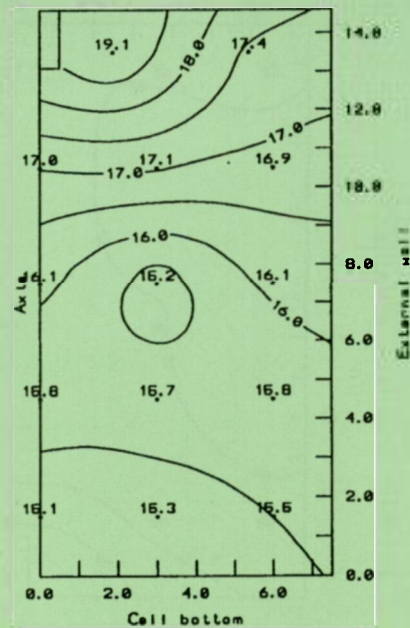
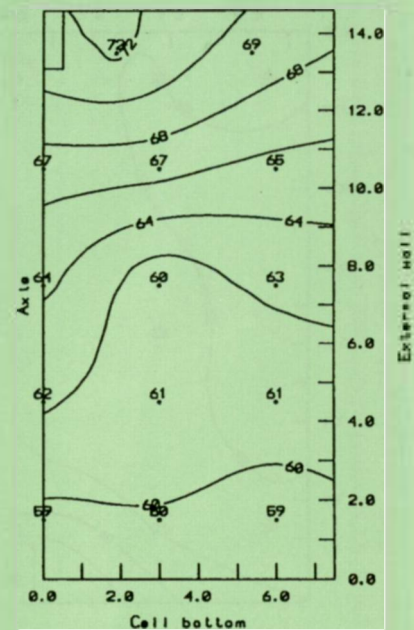


THERMOHYDRAULIC CELL, EX5. T3.



THERMOHYDRAULIC CELL. EX5. FINAL DRY DENS. g/cm³

THERMOHYDRAULIC CELL. EX5. FINAL W %

THERMOHYDRAULIC CELL. EX5. FINAL S_r %

THERMOHYDRAULIC CELL			
Experiment n°:		6	
Material:		Montmorillonite clay S-2	
Initial w:	19%	Initial ρ_d :	1.66 g/cm ³
Sample manufacturing date:		18-1-93	
Heater:		1 cm long	
n° cycles:	12	Hydratation:	In cycle #12

Cycle nº:				1	
Heater power:		37 w	Heater T °C:		82
Lab. T °C:		17-22	Bath 30 °C		No
Start:		22-1-93 10:00 0 h	End:		25-1-93 10:00 23.0 h
Total heating time (hours):		23	Cooling time (hours):		71.3
Remarks:					

Cycle n°:				2	
Heater power:		37 w	Heater T °C:		80
Lab. T °C:		19-20	Bath 30 °C		Yes
Start:		26-1-93 8:20 94.3 h	End:		27-1-93 8:49 118.8 h
Total heating time (hours):		24.5	Cooling time (hours):		122.2
Remarks:			Last 2 days of cooling without bath		

Cycle n°:		3
Heater power:	37 w	Heater T °C: 70
Lab. T °C:	19-23	Bath 30 °C Yes
Start:	1-2-93 11:00 241.0 h	End: 2-2-93 8:30 262.0 h
Total heating time (hours):	21	Cooling time (hours): 177.3
Remarks:		Cooling was not completely recorded

Cycle n°:		4
Heater power:	37 w	Heater T °C: 108
Lab. T °C:	17-20	Bath 30 °C No
Start:	9-2-93 17:44 439.3 h	End: 10-2-93 9:10 454.8 h
Total heating time (hours):	15.5	Cooling time (hours): 7.6
Remarks:		

Cycle n°:		5
Heater power:	37 w	Heater T °C: 107
Lab. T °C:	18-21	Bath 30 °C No
Start:	10-2-93 16:43 462.4 h	End: 11-2-93 9:05 478.8 h
Total heating time (hours):	16.4	Cooling time (hours): 8.2
Remarks:		

Cycle n°:		6
Heater power:	37 w	Heater T °C: 108
Lab. T °C:	21	Bath 30 °C No
Start:	11-2-93 17:30 487.0 h	End: 12-2-93 9:00 502.5 h
Total heating time (hours):	15.5	Cooling time (hours): 72.9
Remarks:		Cooling is not recorded

Cycle n°:		7
Heater power:	37 w	Heater T °C: 109
Lab. T °C:		Bath 30 °C No
Start:	15-2-93 9:58 575.4 h	End: 15-2-93 16:00 581.5h
Total heating time (hours):	6.1	Cooling time (hours): 49.4
Remarks:		Cooling is not recorded

Cycle nº:		8
Heater power:	37 w	Heater T °C: 108
Lab. T °C:	18-20	Bath 30 °C No
Start:	17-2-93 17:30 630.9 h	End: 18-2-93 10:16 647.7 h
Total heating time (hours):	16.8	Cooling time (hours): 5.8
Remarks:		

Cycle nº:		9
Heater power:	37 w	Heater T °C: 109
Lab. T °C:		Bath 30 °C No
Start:	18-2-93 16:01 653.5 h	End: 19-2-92 9:00 670.4 h
Total heating time (hours):	16.9	Cooling time (hours): 7
Remarks:		

Cycle nº:		10
Heater power:	37 w	Heater T °C:
Lab. T °C:	18-22	Bath 30 °C No
Start:	19-2-93 16:00 677.4 h	End: 22-2-93 11:08 744.6 h
Total heating time (hours):	67.2	Cooling time (hours): 21
Remarks:		Heating is not recorded

Cycle nº:		11
Heater power:	37 w	Heater T °C: 109
Lab. T °C:		Bath 30 °C No
Start:	23-2-93 8:11 765.6 h	End: 24-2-93 9:00 790.5 h
Total heating time (hours):	24.9	Cooling time (hours): 10.3
Remarks: Hydratation with running water at 11 bar stars 0.1 hours before next cycle (800.7 h)		

Cycle n°:		12
Heater power:	37 w	Heater T °C: 109
Lab. T °C:	14-24 (19)	Bath 30 °C No
Start:	24-2-93 19:20 800.8 h	End: 24-3-93 9:18 1462.8 h
Total heating time (hours):	662.0	Cooling time (hours): 5.7
Remarks:		

Total duration of experiment: 1468.5 h

Total heating time: 909.8 h

Total hydration time: 667.8 h

Final ρ_d and w : 1.66 g/cm³, 21.2%

THERMOHYDRAULIC CELL. EX6 STEADY STATE TEMPERATURES-THERMOCOUPLES					
Thermo couples	T ₁ (°C)	T ₂ (°C)	T ₃ (°C)	T ₄ (°C)	T ₅ (°C)
1	41	34	32	39	61
2	27	24	23	26	34
3	26	24	24	25	31
4	26	24	24	25	32
5	32	28	27	31	43
6	28	25	25	27	35
7	29	26	26	28	37
8	25	24	24	24	31
9	29	24	24	28	37
Heater 10	84	82	73	100	102

T₁: 22/1/93 22:00, 12 h of cycle 1 (no bath, no hydration), Tamb: 21°C.

T₂: 26/1/93 18:00, 104.0 h, 9.7 h of cycle 2 (with bath, no hydration).

T₃: 1/2/93 18:00, 247.5 h, 6.5 h of cycle 3 (with bath, no hydration).

T₄: 2/3/93 18:00, 943.5 h, 142.8 h of cycle 12 (no bath, hydration 10 bar), Tamb: 20°C.

T₅: 13/3/93 18:00, 1207.5 h, 406.0 h of cycle 12 (no bath, hydration 10 bar), Tamb: 20.5°C. After 2nd adjustment of thermocouples.

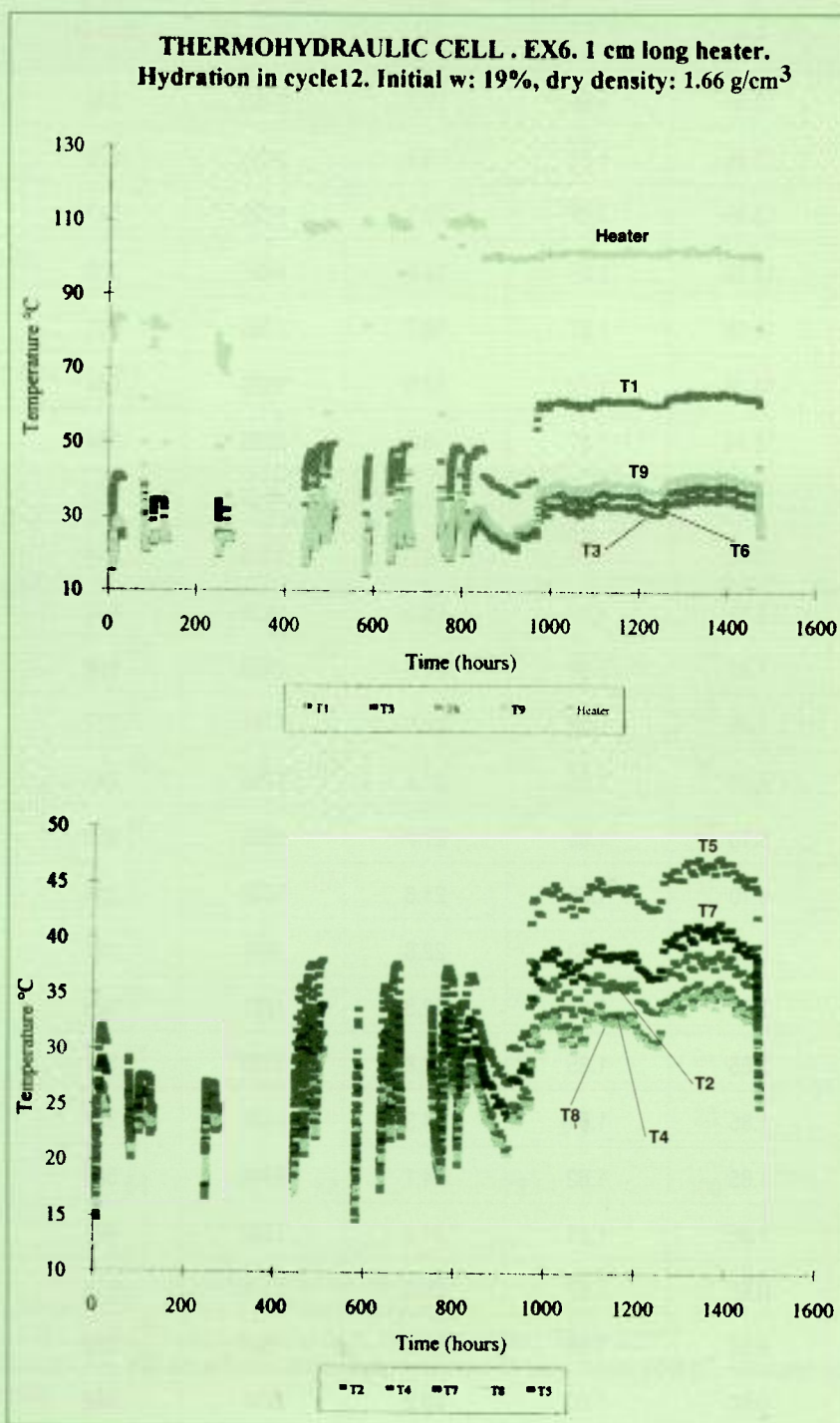
THERMOHYDRAULIC CELL. EX6 FINAL CHARACTERISTICS AT DIFFERENT LEVELS						
x cm	y cm	ρ_d g/cm ³ (1)	w % (1)	EC ₂₅ °C S/cm (2)	SiO ₂ ppm (4)	Specif. surface BET m ² /g
1.25	13.85	1.69	16.7	3166	240	19
3.75	13.85	1.71	18.3	3456	575	
6.25	13.85	1.67	19.3	1638	347	19
3.00	12.35	1.67	18.2	1697	310	
6.00	12.35	1.67	18.7	1753	271	38
0.00	12.35	1.72	17.0	1626	354	27
3.00	10.10	1.67	18.8	1045	359	
6.00	10.10	1.67	19.3	923	400	39
0.00	10.10	1.68	18.0	1554	554	35
3.00	7.35	1.66	20.0	1606	422	
6.00	7.35	1.66	20.5	1550	588	
0.00	7.35	1.65	20.0	1791	707	
3.00	6.10	1.65	21.5	1750	247	
6.00	6.10	1.65	21.7	1565	996	
0.00	6.10	1.65	21.6	1400	294	37
3.00	3.85	1.63	22.8	893	541	
6.00	3.85	1.64	22.8	1221	525	35
0.00	3.85	1.65	22.8	1185	347	
3.00	1.85	1.61	24.3	1400	324	
6.00	1.85	1.62	24.1	1648	589	42
0.00	1.85	1.61	24.2	1707	401	
3.00	0.60	1.57	26.5	1178	318	
6.00	0.60	1.56	27.3	1560	289	
0.00	0.60	1.60	26.2	939	348	

(1) Average of 2 symmetric points.

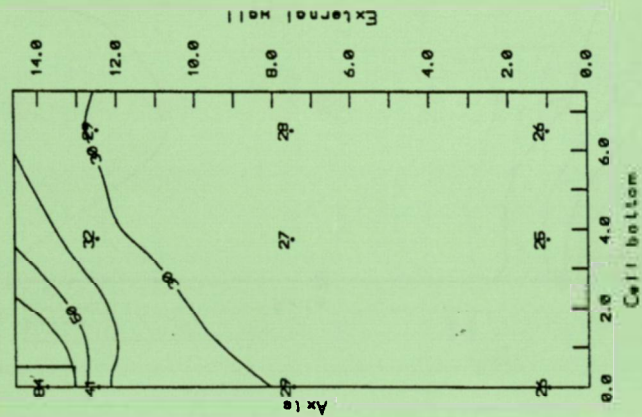
(2) Electrical conductivity of the 1:5 extract of the air dried sample. 1 measure.

(3) In the 1:5 extract of the air dried sample. 1 measure.

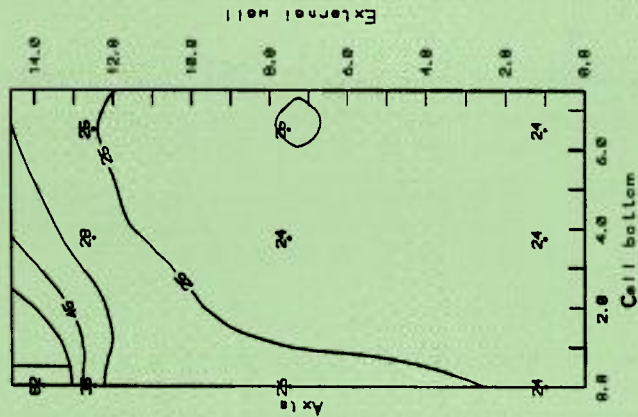
(4) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation (in the air dried sample). 1 measure.



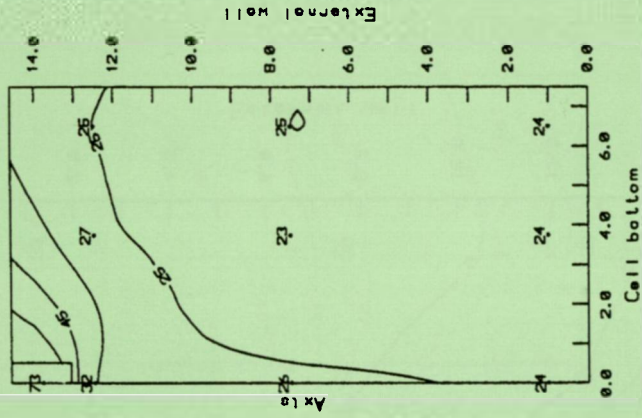
THERMOHYDRAULIC CELL. EX6. T1.



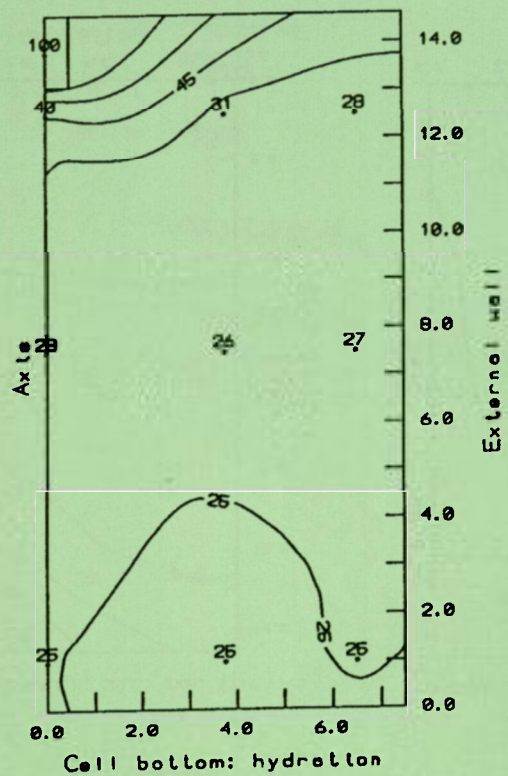
THERMOHYDRAULIC CELL. EX6. T2.



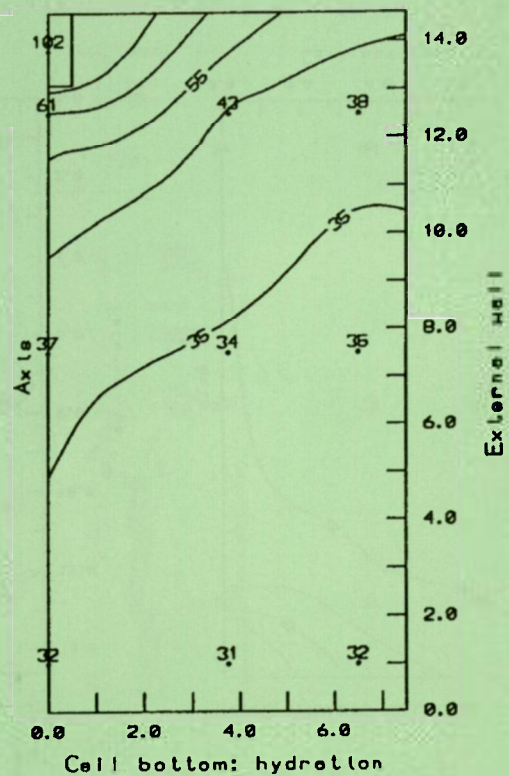
THERMOHYDRAULIC CELL. EX6. T3.



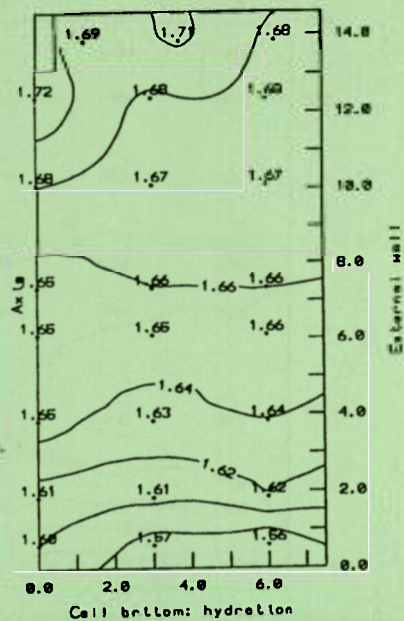
THERMOHYDRAULIC CELL. EX6. T4.



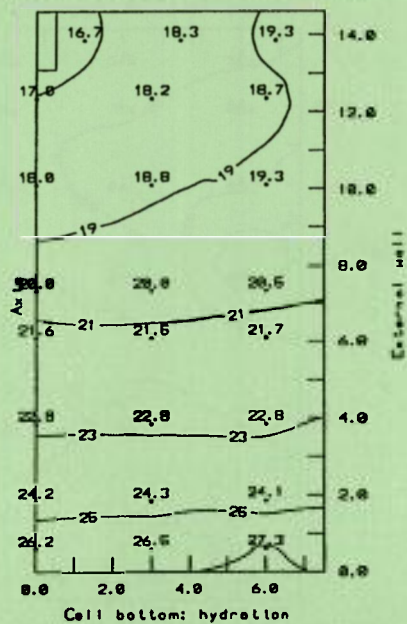
THERMOHYDRAULIC CELL. EX6. T5.



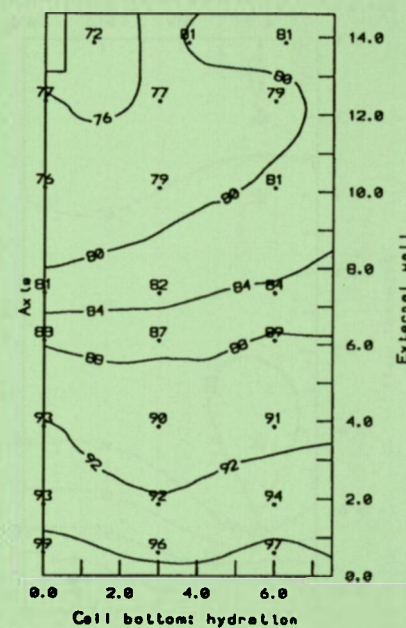
THERMOHYDRAULIC CELL, EX6. FINAL DRY DENS. g/cm^3



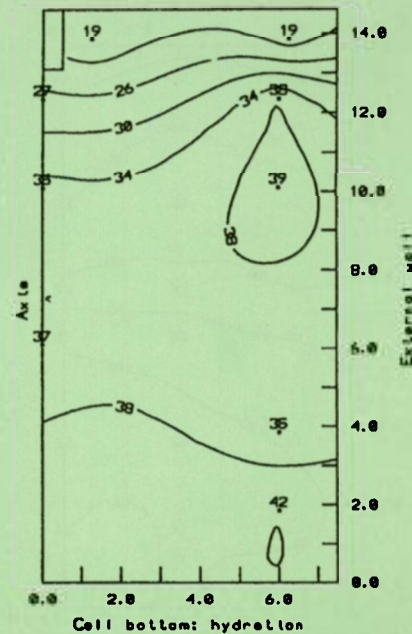
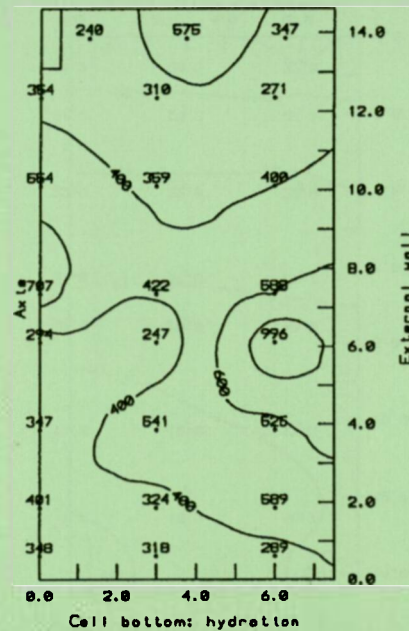
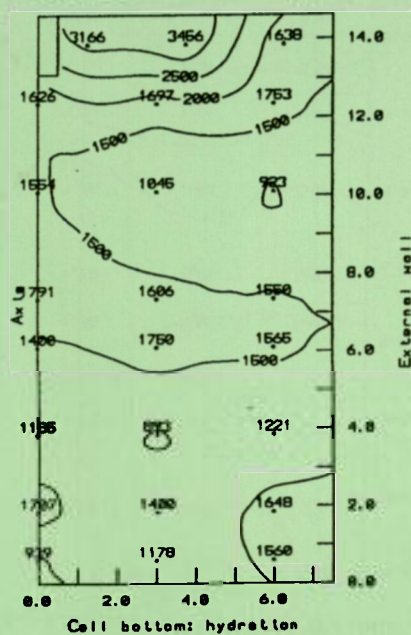
THERMOHYDRAULIC CELL, EX6. FINAL μ



THERMOHYDRAULIC CELL, EX6. FINAL Sr



THERMOHYDRAULIC CELL. EX6. FINAL $EC_{\mu S/cm}$ THERMOHYDRAULIC CELL. EX6. FINAL FREE SILICA ppm THERMOHYDRAULIC CELL. EX6. FINAL BET m^2/g



THERMOHYDRAULIC CELL			
Experiment n°:		7	
Material:		Montmorillonite clay S-2	
Initial w:	11.4%	Initial pd:	1.64 g/cm ³
Sample manufacturing date:		13-4-93	
Heater:		Axial	
n° cycles:	4	Hydratation:	No

Cycle n°:			
Heater power:	22.5 w	Heater T °C:	87
Lab. T °C:	recorded	Bath 30 °C	No
Start:	20-4-93 11:50 0 h	End:	26-4-93 11:00 142.2 h
Total heating time (hours):	142.2	Cooling time (hours):	52
Remarks:		Thermocouples were repaired several times	

Cycle n°:			
Heater power:	22.5 w	Heater T °C:	86
Lab. T °C:	recorded	Bath 30 °C	No
Start:	28-4-93 14:00 194.2 h	End:	30-4-93 6:00 234 h
Total heating time (hours):	39.8	Cooling time (hours):	100.4
Remarks:			

Cycle n°:			
Heater power:	40 w	Heater T °C:	86
Lab. T °C:	recorded	Bath 30 °C	No
Start:	4-5-93 10:24 334.4 h	End:	5-5-93 9:00 357.0 h
Total heating time (hours):	22.6	Cooling time (hours):	122.4
Remarks:		Only 6 hours of cooling recorded	

Cycle n°:		4
Heater power:	40 w	Heater T °C: 87
Lab. T °C:	recorded	Bath 30 °C No
Start:	110-5-93 11:26 479.4 h	End: 20-5-93 12:00 720.0 h
Total heating time (hours):	240.6	Cooling time (hours): 27.1
Remarks:		

Total duration of experiment: 747.1 h (31 days)

Total heating time: 445.2 h (18.5 days)

Demoulding: 21-5-93

Final ρ_d and w: 1.64 g/cm³, 11.3%

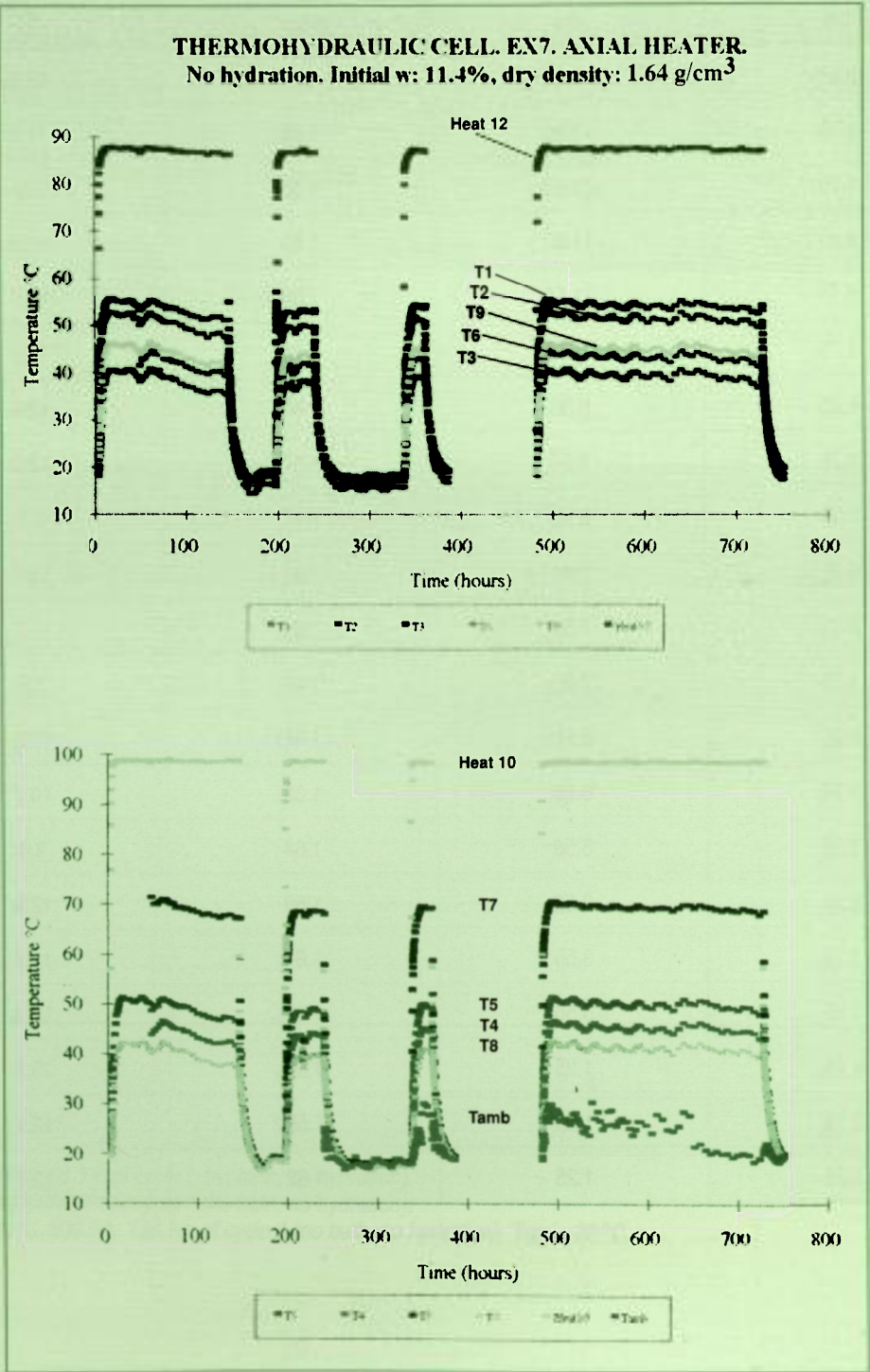
THERMOHYDRAULIC CELL. EX7 STEADY STATE TEMPERATURES-THERMOCOUPLES			
Thermocouple	T ₁ (°C)	T ₂ (°C)	T ₃ (°C)
1	55	55	54
2	52	52	51
3	40	40	39
4	46	46	45
5	51	50	50
6		44	43
7		70	69
8	42	42	41
9	46	45	45
Heater (10)	99	99	98

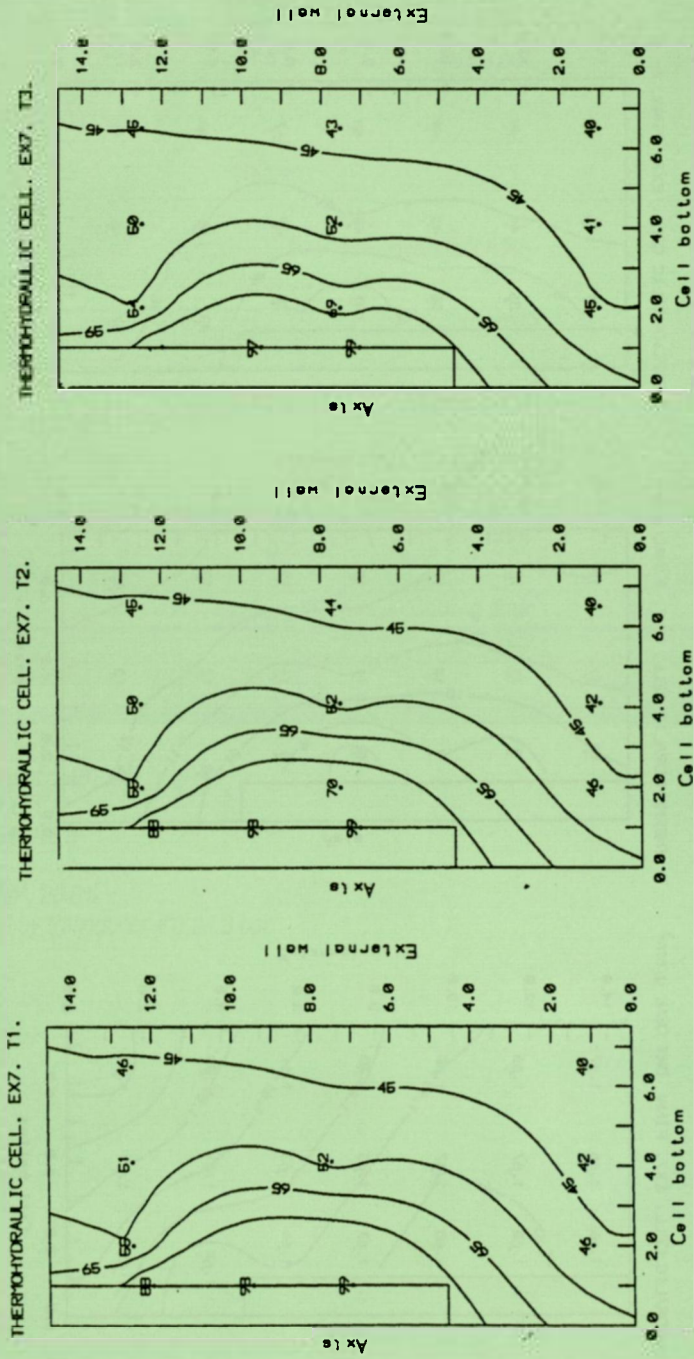
T₁: 21/4/93 18:30, 30.7 h of cycle 1 (no bath, no hydration).

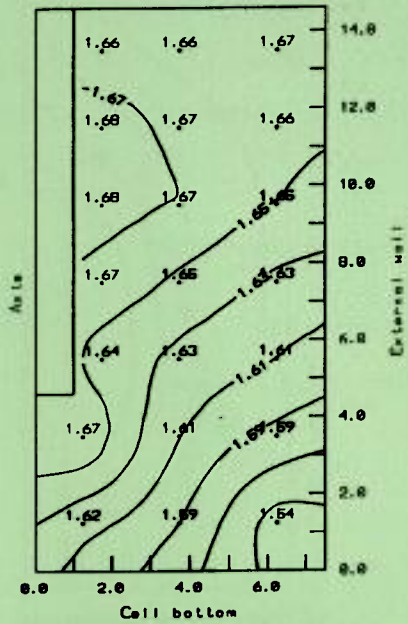
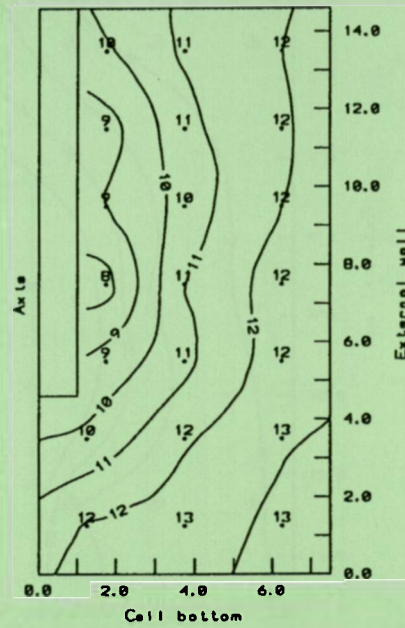
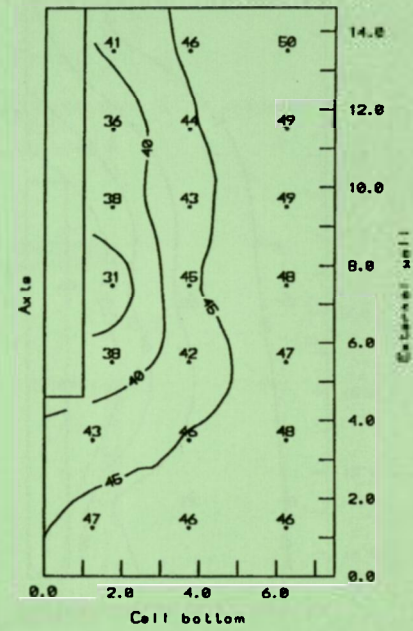
T₂: 22/4/93 18:00, 54.2 h of cycle 1 (no bath, no hydration).

T₃: 15/5/93 18:00, 606.0 h, 126.6 h of cycle 4 (no bath, no hydration), T_{amb}: 22 °C.

THERMOHYDRAULIC CELL. EX7 FINAL DRY DENSITY AND WATER CONTENT			
x cm	y cm	Dry density g/cm ³	Water content %
6.25	13.50	1.67	12.0
3.75	13.50	1.66	11.2
1.75	13.50	1.66	9.9
6.25	11.50	1.65	11.9
3.75	11.50	1.66	10.7
1.75	11.50	1.68	8.5
6.25	9.50	1.65	12.0
3.75	9.50	1.67	10.3
1.75	9.50	1.67	9.1
6.25	7.50	1.63	12.4
3.75	7.50	1.64	11.1
1.75	7.50	1.66	7.5
6.25	5.50	1.61	12.3
3.75	5.50	1.63	10.7
1.75	5.50	1.64	9.4
6.25	3.50	1.59	12.9
3.75	3.50	1.61	11.9
1.25	3.50	1.67	10.2
6.25	1.25	1.54	13.2
3.75	1.25	1.59	12.5
1.25	1.25	1.62	12.1





THERMOHYDRALIC CELL. EX7. FINAL DRY DEN. g/cm^3 THERMOHYDRALIC CELL. EX7. FINAL w %THERMOHYDRALIC CELL. EX7. FINAL S_r %

THERMOHYDRAULIC CELL			
Experiment n°:		8	
Material:		Montmorillonite clay S-2	
Initial w:	11.8%	Initial ρ_d :	1.66 g/cm ³
Sample manufacturing date:			
Heater:		Axial	
n° cycles:	1	Hydratation:	No Deionized water 11 bar

Cycle n°:			
Heater power:	40 w	Heater T °C:	96.5
Lab. T °C:		Bath 30 °C	No
Start:	7-6-93 17:25 0 h	End:	15-9-93 15:00 2401.6 h
Total heating time (hours):	2401.6 h	Cooling time (hours):	
Remarks:			

Demoulding: 15-9-93

Total duration of experiment: 2401.6 h

Total heating time: 2401.6 h

Total hydration time: 2401.6 h

Water uptake: 382 cm³

Final ρ_d and w: 1.65 g/cm³, 20.0%

Final pressure registered by transducer #1: 34.3 bar

THERMOHYDRAULIC CELL. EX8 STEADY STATE TEMPERATURES-THERMOCOUPLES				
Thermocouples	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)
1	57	56	58	57
2	55	53	55	54
3	42	41	43	42
4	48	46	49	47
5	54	52	55	53
6	46	45	47	46
7	72	70	73	71
8	43	42	45	43
9	47	46	48	47
Heater 10	88	88	90	88

T_1 : 8/6/93 18:00, 25.6 h, T_{amb} : 24°C.

T_2 : 5/8/93 18:00, 1420.6 h, T_{amb} : 23.5°C.

T_3 : 14/9/93 18:00, 2380.6 h, T_{amb} : 22.5°C.

T_4 : Average of the values from 100 h on. T_{amb} : 25°C.

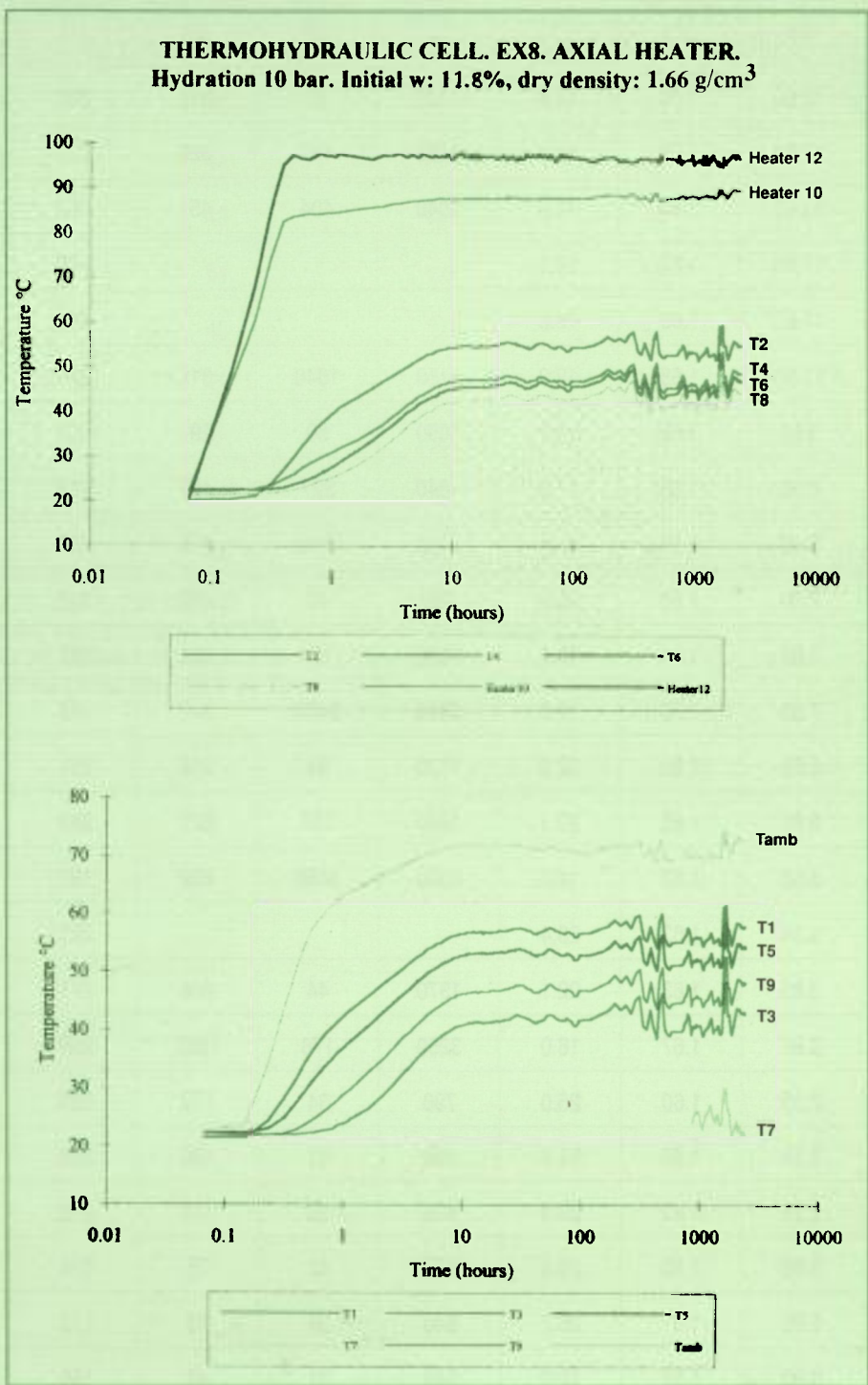
THERMOHYDRAULIC CELL. EX8
FINAL CHARACTERISTICS AT DIFFERENT LEVELS

x cm	y cm	ρ_d g/cm ³ (1)	w % (1)	EC ₂₅ C S/cm (2)	Cl ⁻ ppm (3)	SO ₄ ⁼ ppm (3)	SiO ₂ ppm (4)	Specif. surface BET m ² /g
6.25	13.60	1.69	18.6	1120	91	312	260	
3.75	13.60	1.66	17.2	1180	117	322	273	
1.75	13.60	1.64	14.6	2040	404	451	262	
6.25	11.60	1.67	19.1				276	49
3.75	11.60	1.65	16.8				244	44
1.75	11.60	1.68	12.3	5150	1640	319	206	19
6.25	9.60	1.66	19.7	1050	50	291	262	
3.75	9.60	1.65	17.0	1840	227	427	218	
1.75	9.60	1.70	11.4	6740	2540	318	188	
6.25	7.60	1.65	20.8	950	40	272	237	43
3.75	7.60	1.64	18.2	1830	152	502	221	
1.75	7.60	1.70	11.8	6810	2470	377	188	15
6.25	5.60	1.63	22.0	1130	34	315	261	
3.75	5.60	1.65	20.1	1660	107	627	243	
1.75	5.60	1.67	14.0	4930	1480	669	187	
6.25	3.85	1.63	23.4				221	49
3.75	3.85	1.63	22.1	1370	44	606	211	
1.25	3.85	1.67	18.0	3250	176	1560	209	24
6.25	2.35	1.60	25.0	790	34	170	225	
3.75	2.35	1.60	24.6	690	31	150	228	
1.25	2.35	1.62	23.3	830	32	133	212	
6.25	0.80	1.50	28.4	650	42	75	114	
3.75	0.80	1.51	28.7	640	34	76	112	50
1.25	0.80	1.52	28.0	550	31	49	156	

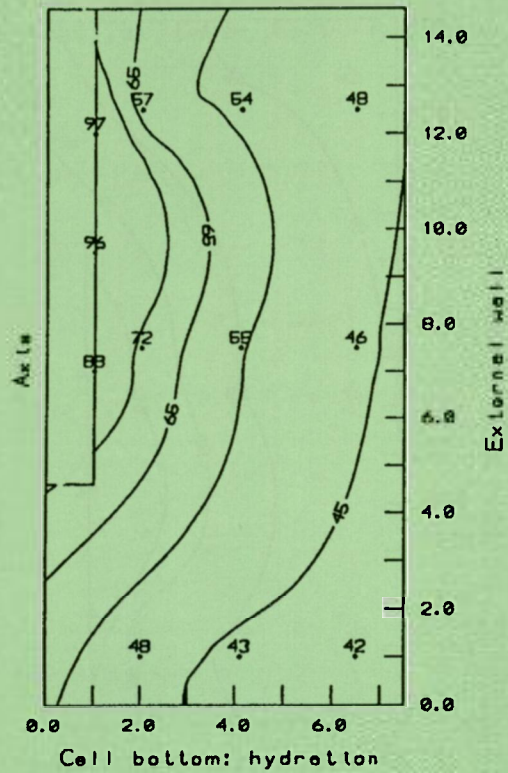
(1) Average of 2 symmetric points.

(2) Electrical conductivity of the 1:5 extract of the air dried sample. 1 measure.

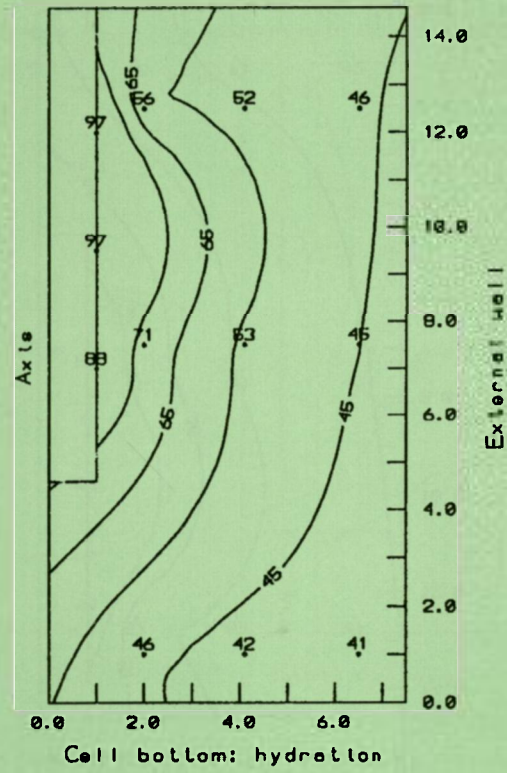
(3) In the 1:5 extract of the air dried sample. 1 measure.



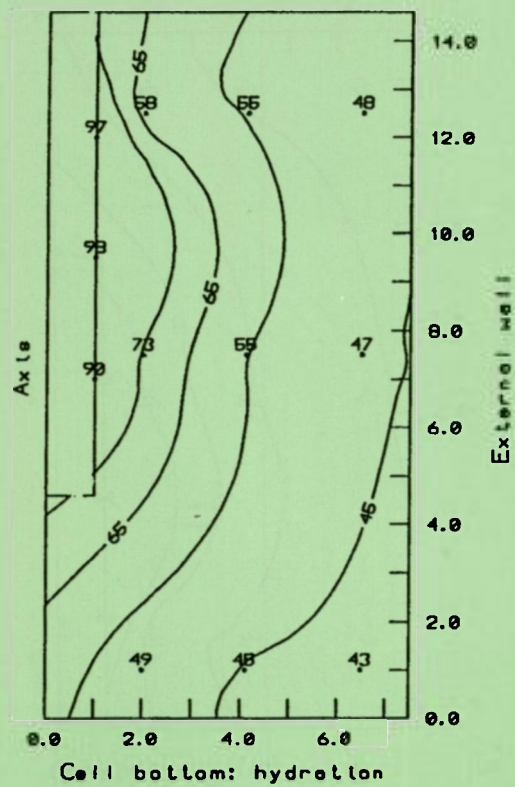
THERMOHYDRAULIC CELL. EXB. T1.



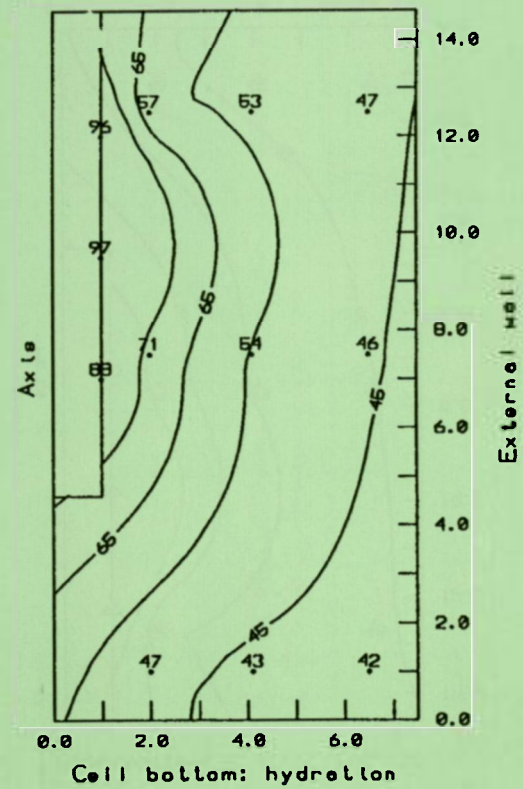
THERMOHYDRAULIC CELL. EXB. T2.



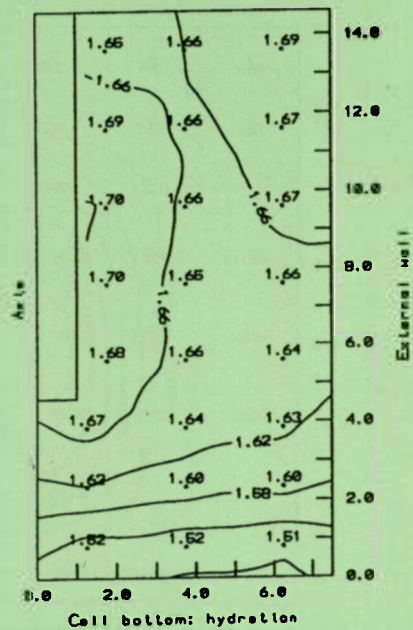
THERMOHYDRAULIC CELL. EXB. T3.



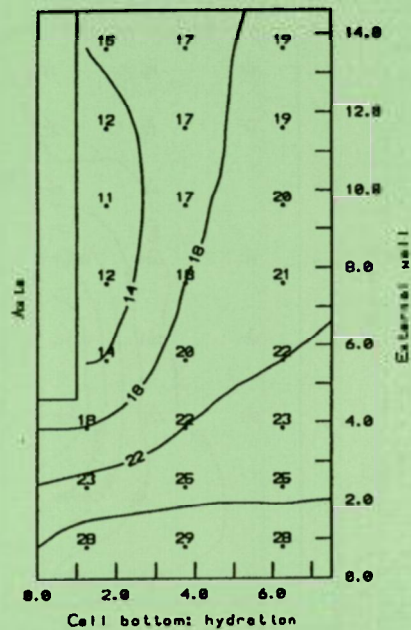
THERMOHYDRAULIC CELL. EXB. T4.



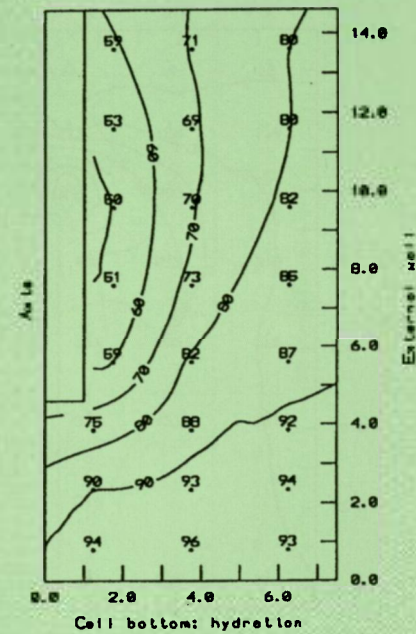
THERMOHYDRALIC CELL. EXB. FINAL DRY DEN. g/cm^3

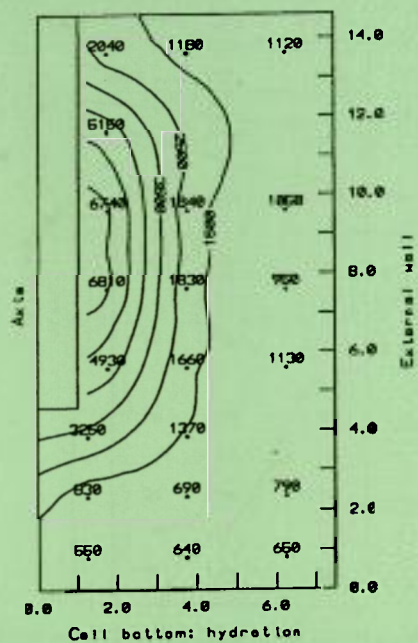


THERMOHYDRALIC CELL. EXB. FINAL W %

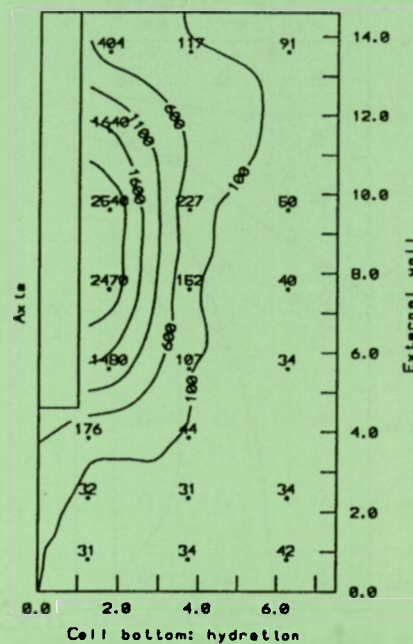


THERMOHYDRALIC CELL. EXB. FINAL S_r %

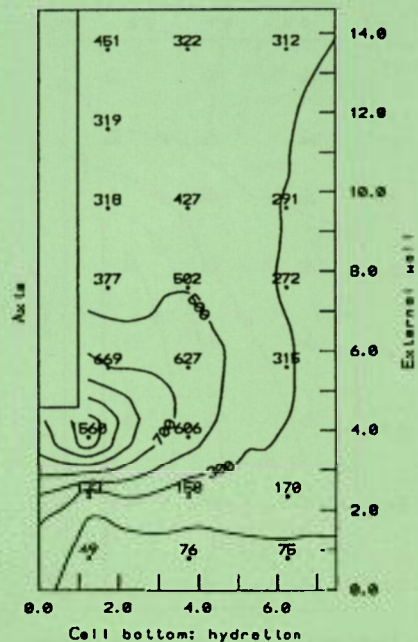


THERMOHYDRAULIC CELL. EXB. EC 25 C $\mu\text{S/cm}$ 

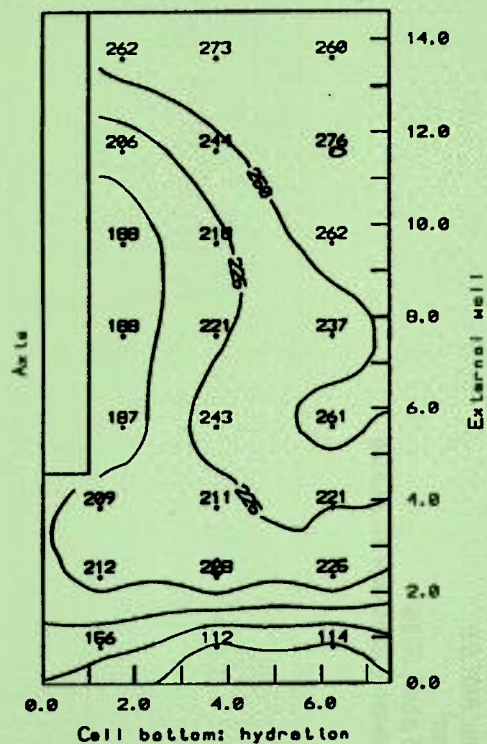
THERMOHYDRAULIC CELL. EXB. CHLORIDES ppm



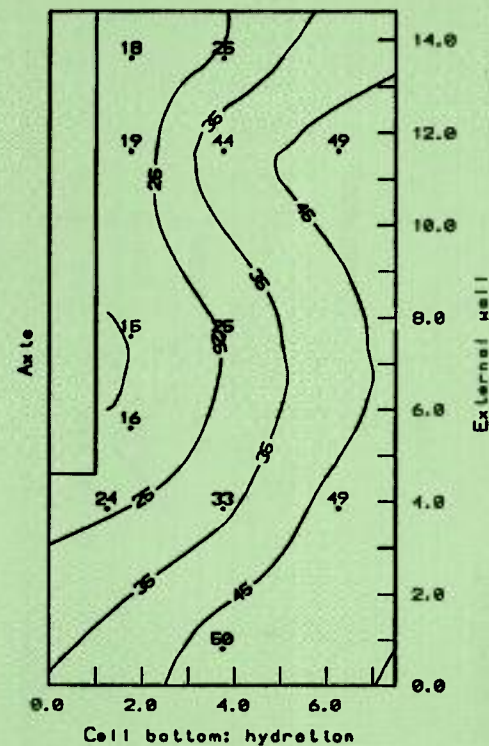
THERMOHYDRAULIC CELL. EXB. SULPHATE ppm



THERMOHYDRAULIC CELL. EX8. FREE SILICA ppm



THERMOHYDRAULIC CELL. EX8. FINAL BET m2/g



THERMOHYDRAULIC CELL			
Experiment n°:		9	
Material:		Montmorillonite clay S-2	
Initial w:	17.1%	Initial pd:	1.69 g/cm ³
Sample manufacturing date:		8-11-93	
Heater:		Axial	
n° cycles:	1	Hydratation:	Deionized water 10 bar

Cycle n°:		1	
Heater power:	40 w	Heater T °C:	95.7
Lab. T °C:	recorded	Bath 30 °C	No
Start:	17-11-93 9:45 0 h	End:	5-5-93 16:11 4062.4 h
Total heating time (hours):	4062.4	Cooling time (hours):	
Remarks:			

Demoulding: 15-9-93

Total duration of experiment: 2401.6 h

Total heating time: 2401.6 h

Total hydration time: 2401.6 h

Water uptake: 382 cm³

Final ρ_d and w: 1.65 g/cm³, 20.0%

Final pressure registered by transducer #1: 34.3 bar

THERMOHYDRAULIC CELL. EX9 STEADY STATE TEMPERATURES-THERMOCOUPLES			
Thermocouple	T ₁ (°C)	T ₂ (°C)	T ₃ (°C)
1	55	56	61
2	53	53	57
3	41	41	43
4	47	47	49
5	52	52	55
6	45	45	48
7	73	73	78
8	43	43	45
9	46	46	49
Heater 10	99	98	99

T₁: 18/11/93 18:00, 32.2 h. Tamb: 20.3 °C.

T₂: Average of the measures between 101.2 h (21/11/93 15:00) and 992.2 h (28/12/93 18:00), Tamb: 20.1 °C.

T₃: 19/4/94 18:00, 3680.3 h. Tamb: 20.1 °C

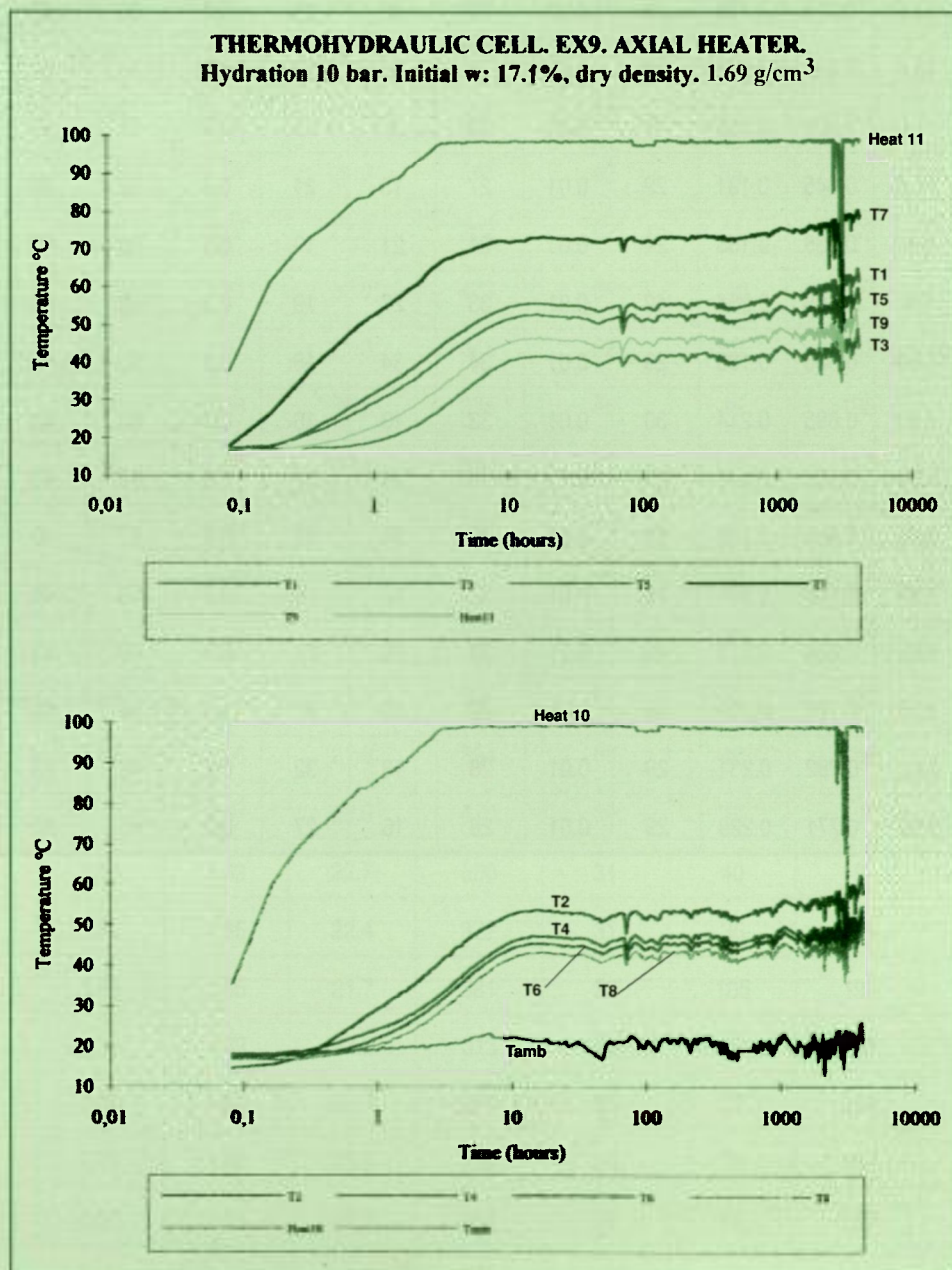
THERMOHYDRAULIC CELL. EX9 FINAL CHARACTERISTICS AT DIFFERENT LEVELS								
x cm	y cm	ρ_d g/cm ³ (1)	w % (1)	EC ₂₅ c μ S/cm (2)	Cl ⁻ ppm (3)	SO ₄ ⁼ ppm (3)	SiO ₂ ppm (4)	Specif. surface BET m ² /g
6.25	13.60	1.69	20.4	322	60	35	264	26
3.75	13.60	1.70	20.4	351	63	30	195	24
1.75	13.60	1.67	19.6	393	63	62	197	24
6.25	11.60	1.69	21.3	345	62	36	192	28
3.75	11.60	1.70	21.0	362	62	46	198	28
1.75	11.60	1.71	20.0	473	68	114	197	24
6.25	9.60	1.67	21.0	345	52	30	192	26
3.75	9.60	1.68	20.8	375	56	45	198	26
1.75	9.60	1.70	19.6	461	56	116	197	26
6.25	7.60	1.64	21.7	330	45	31	65	25
3.75	7.60	1.68	21.3	350	47	60	195	26
1.75	7.60	1.70	20.3	442	46	125	132	22
6.25	5.60	1.63	21.9	396	67	59	130	25
3.75	5.60	1.66	21.9	354	58	46	194	24
1.75	5.60	1.67	20.9	470	34	162	197	24
6.25	3.85	1.63	22.7	330	31	40	197	26
3.75	3.85	1.65	22.4	322	31	35	195	26
1.25	3.85	1.65	21.7	381	32	105	192	26
6.25	2.35	1.63	23.2	313	26	27	256	26
3.75	2.35	1.63	22.7	294	25	22	258	29
1.25	2.35	1.65	22.5	256	26	23	197	29
6.25	0.80	1.54	25.7	257	22	19	257	30
3.75	0.80	1.57	25.4	271	23	19	198	30
1.25	0.80	1.56	25.3	282	24	19	194	32

(1) Average of 2 symmetric points.

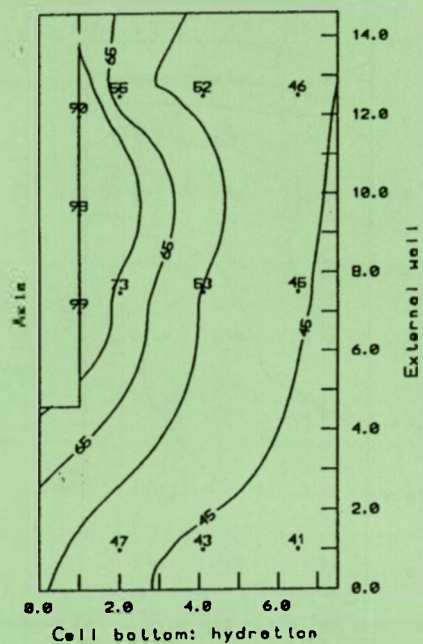
(2) Electrical conductivity of the 1:5 extract of the air dried sample. 1 measure.

(3) In the 1:5 extract of the air dried sample. 1 measure.

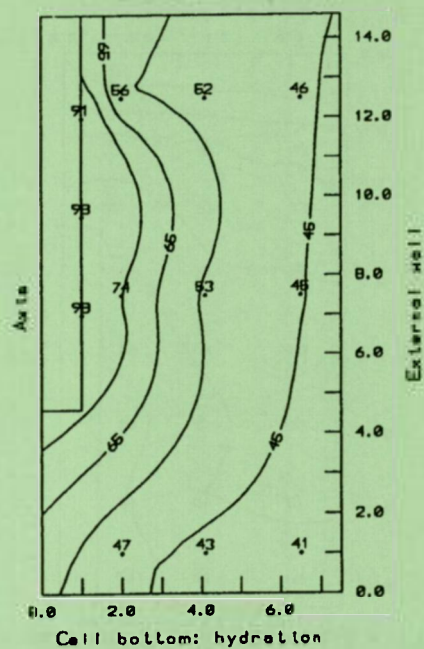
THERMOHYDRAULIC CELL. EX9 MERCURY POROSIMETRY DATA.												
x (cm)	y (cm)	e ₁	e ₂	% total	medium φ (μ)	% large	Mode large (μ)	% medium	Mode medium (μ)	% s mall	Mode small (Å)	Unif. coef.
3.75	13.6	0.635	0.178	28	0.02	27	10	23	0.2	50	63	31
6.25	13.6	0.645	0.173	26	0.01	28	10	19	0.3	53	50	51
1.75	11.6	0.626	0.258	41	0.01	19	5	20	0.3	61	63	14
6.25	11.6	0.645	0.191	29	0.01	27	13	21	0.3	52	63	65
1.75	9.6	0.635	0.155	24	0.01	24	21	19	0.3	58	63	19
6.25	9.6	0.665	0.284	42	0.01	33	27	19	0.3	48	63	65
1.75	7.60	0.635	0.189	29	0.01	34	34	16	0.3	50	63	107
6.25	7.60	0.695	0.214	30	0.01	33	13	16	0.3	50	63	83
6.25	5.60	0.705	0.148	20	0.01	14	34	27	0.8	59	63	91
1.25	3.85	0.685	0.138	20	0.01	26	34	22	0.1	52	40	39
6.25	3.85	0.705	0.274	38	0.01	32	13	16	0.3	52	40	65
1.25	2.35	0.685	0.277	40	0.01	30	10	21	0.3	49	63	65
6.25	2.35	0.705	0.201	28	0.01	29	10	21	1.1	50	63	51
1.25	0.80	0.782	0.231	29	0.01	28	13	32	0.3	40	63	51
3.75	0.80	0.771	0.229	29	0.01	28	16	27	0.3	45	63	51



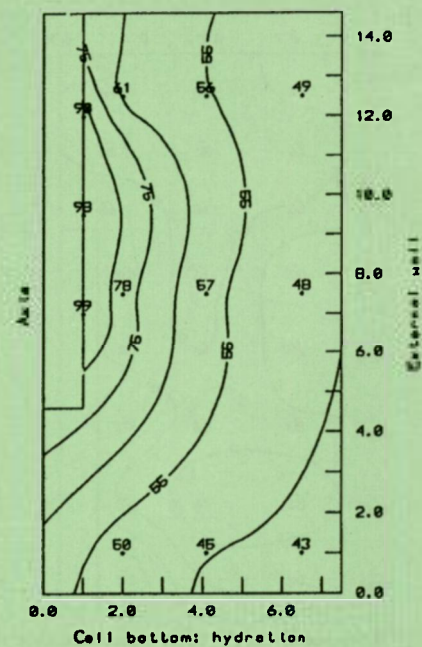
THERMOHYDRAULIC CELL. EX9. T1.

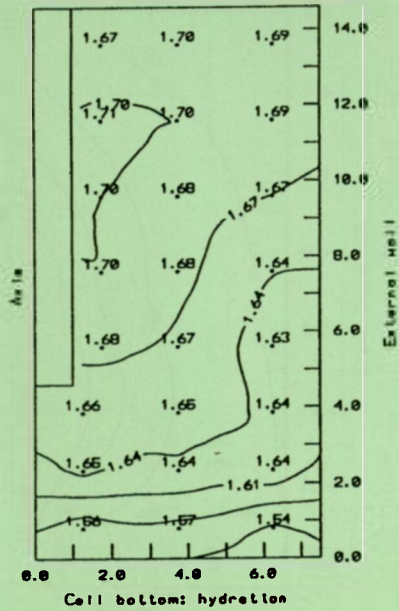


THERMOHYDRAULIC CELL. EX9. T2.

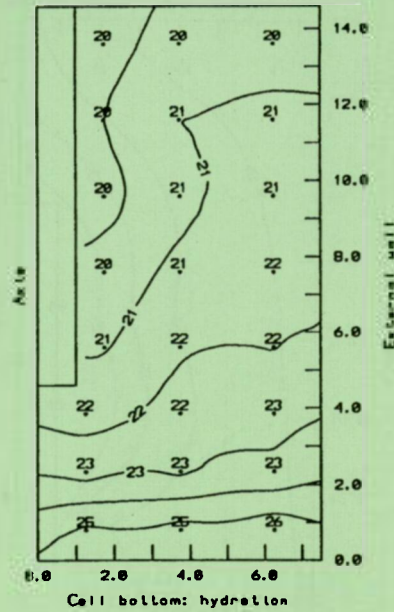
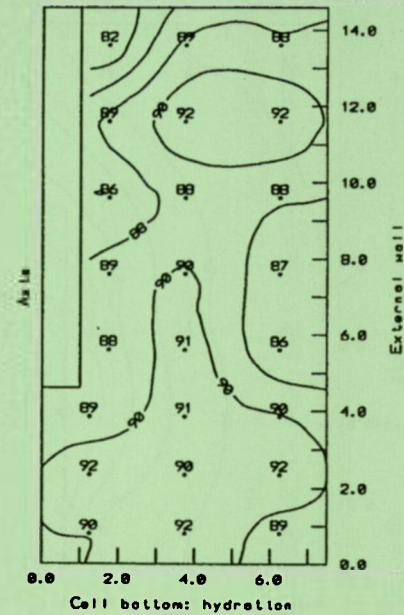


THERMOHYDRAULIC CELL. EX9. T3.

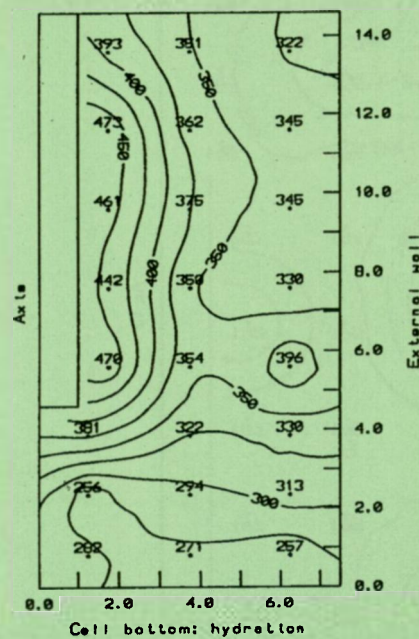


THERMOHYDRALIC CELL. EX9. FINAL DRY DEN. g/cm³

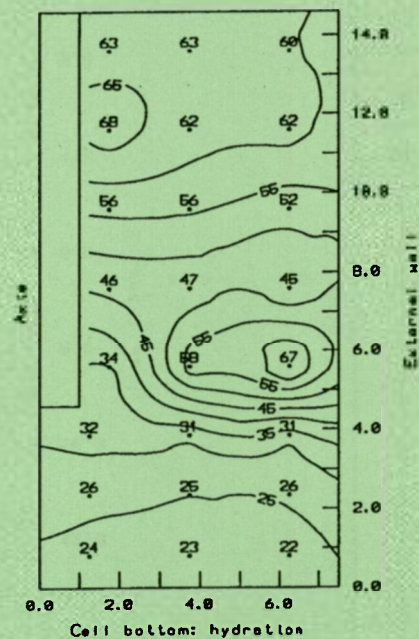
THERMOHYDRALIC CELL. EX9. FINAL w %

THERMOHYDRALIC CELL. EX9. FINAL S_r %

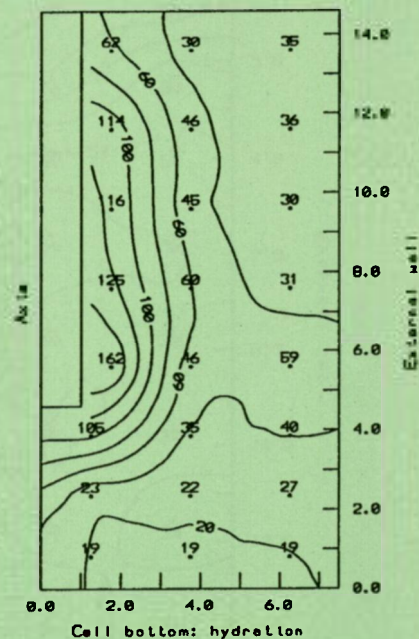
THERMOHYDRAULIC CELL. EX9. EC. $\mu S/cm$



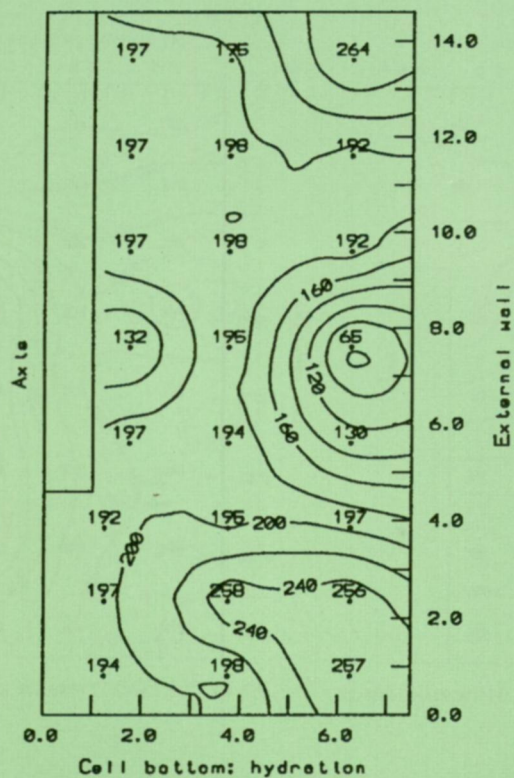
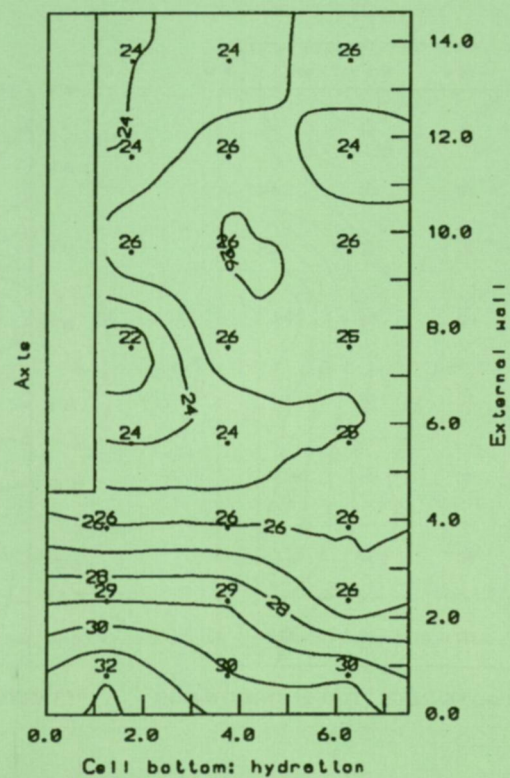
THERMOHYDRAULIC CELL. EX9. CLORURES ppm



THERMOHYDRAULIC CELL. EX9. SULPHATES ppm



THERMOHYDRAULIC CELL. EX9. FREE SILICA ppm

THERMOHYDRAULIC CELL. EX9. BET m²/g

ANNEX II

ANNEX II

4 days Ex3	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.65	21.1	887	53	208	189	29
2	1.68	19.1	1557	192	414	172	30
3	1.69	16.9	1961	384	357	165	30
4	1.66	14.8	1913	380	323	185	18
5	1.69	13.9	1858	336	350	211	9?
6	1.69	8.7	2169	502	313	261	8?

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX3. Oven dried.

Sample	e ₁	e ₂	% total	medium φ	% large	Mode large μ	% medium	Mode medium μ	% small	Mode small μ	Uniformity coef.
1	0.685	0.267	39	0.01	22	10	18	0.20	60	0.008	12
2	0.655	0.267	41	0.01	16	10	26	0.20	58	0.008	15
3	0.645	0.243	37	0.01	15	5	31	0.26	52	0.007	27
4	0.675	0.307	45	0.01	22	6	30	0.20	48	0.008	83
5	0.645	0.225	35	0.01	16	9	37	0.86	47	0.008	96

5 days Ex5	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.59	24.0	1171	68	288	528	48
2	1.65	18.4	1740	234	375	158	44
3	1.62	15.4	2577	465	483	142	34
4	1.64	12.3	1847	285	326	184	30
5	1.67	8.6	1926	347	321	140	24

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX5. Oven dried.

Sample	e ₁	e ₂	% total	medium φ	% large	Mode large μ	% medium	Mode medium μ	% small	Mode small μ	Uniformity coef.
1	0.748	0.230	31	0.04	38	6.13	38	0.321	24	0.006	65
2	0.685	0.188	27	0.13	44	6.13	42	0.321	14	0.017	31
3	0.716	0.193	27	0.17	40	6.13	49	0.321	12	0.035	19
4	0.695	0.242	35	0.01	24	6.13	36	0.321	40	0.006	65
5	0.665	0.263	39	0.01	20	21.0	20	0.321	60	0.006	12

13 days Ex6	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.67	20.9	1568	129	382	164	26
2	1.69	18.7	1624	223	303	168	26
3	1.68	17.2	1969	384	336	154	22
4	1.67	14.4	2185	449	290	130	21
5	1.71	9.1	3465	944	270	133	26

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX6. Oven dried.

Sample	e1	e2	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1	0.665	0.179	27	0.01	15	7.8	20	0.321	65	0.006	6
2	0.645	0.198	31	0.01	14	4.8	30	0.321	56	0.006	15
3	0.655	0.199	30	0.01	16	6.13	31	0.196	52	0.006	31
4	0.665	0.252	38	0.01	28	6.13	32	0.321	40	0.006	137
5	0.626	0.232	37	0.01	26	6.13	32	0.321	42	0.006	107

17 days Ex9 No hydration	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.67	11.2	1497	274	310	587	23
2	1.64	10.2	1826	310	300	539	24
3	1.66	6.5	1712	355	291	543	24
4	1.71	6.4	1816	397	304	567	20
5			2100	531	293	524	19

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX9. NO HYDRATION. Freeze dried.

Sample	e ₁	e ₂	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1	0.665	0.199	30	0.01	14	4.8	36	0.321	50	0.006	40
2	0.695	0.264	38	0.01	15	3.7	36	0.321	49	0.006	51
3	0.675	0.218	32	0.01	22	4.8	32	0.321	46	0.006	84
4	0.626	0.196	31	0.01	11	3.7	37	0.321	52	0.006	40
5											

20 days Ex4	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.67	20.7	993	53	168	119	52
2	1.69	20.0	1569	83	389	184	49
3	1.69	18.5	1527	109	337	249	43
4	1.68	15.1	1642	178	293	165	16
5	1.73	10.4	3194	763	301	178	10

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX4. Freeze dried.

Sample	e ₁	e ₂	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1	0.665	0.221	33	0.01	24	6.1	34	0.321	42	0.006	107
2	0.645	0.260	40	0.01	22	6.1	34	0.321	44	0.005	67
3	0.645	0.188	29	0.01	14	4.8	32	0.321	54	0.006	19
4	0.655	0.182	28	0.01	17	4.8	28	0.321	55	0.006	19
5	0.607	0.238	39	0.01	18	3.7	21	0.321	61	0.006	9

21 days Ex10 No hydration	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1		11.2				330	14
2		10.4				343	14
3	1.63	10.0				255	14
4	1.70	8.7				106	14
5	1.78	6.0				116	11

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX10. NO HYDRATION.

Sample	e ₁	e ₂	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1											
2											
3											
4											
5	0.562	0.179	32	0.01	9	3.7	37	0.321	53	0.006	24

26 days Ex7	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ²⁻ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.52	22.6	601	27	81	404	33
2	1.65	20.2	1228	73	368	362	30
3	1.67	17.1	1399	192	373	271	24
4	1.67	13.5	1480	265	318	305	18
5	1.69	8.8	2862	804	309	306	13

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX7. Freeze dried.

Sample	e1	e2	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1											
2	0.685	0.191	23	0.01	19	7.8	28	0.321	53	0.006	19
3	0.665	0.195	29	0.01	14	4.8	29	0.321	57	0.006	19
4	0.665	0.195	29	0.01	23	6.1	30	0.321	47	0.006	51
5	0.645	0.224	35	0.01	33	7.8	30	0.321	37	0.006	137

34 days Ex8	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.65	23.4	666	46	95	126	
2	1.64	22.0	1019	47	321	124	
3	1.62	21.0	1135	61	358	141	
4	1.64	19.2	1118	87	297	140	
5	1.63	17.0	3699	1028	365	116	

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX8.

Sample	e1	e2	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1											
2											
3											
4											
5											

48 days Ex11	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.62	22.9	560	6	21	300	31
2	1.61	17.4	1380	35	521	447	24
3	1.65	13.9	1370	168	312	315	18
4	1.64	10.5	1832	410	250	327	13
5	1.73	6.4	2703	667	238	289	8

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX11. Freeze dried.

Sample	e ₁	e ₂	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1	0.679	0.220	32.4	0.01	27	12.8	24	0.26	48	0.006	35
2	0.689	0.203	29.5	0.01	9	4.8	39	0.32	52	0.006	15
3	0.648	0.244	37.6	0.01	11	4.8	42	0.32	46	0.006	35
4	0.658	0.219	33	0.01	23	4.8	36	0.32	40	0.006	84
5	0.572	0.363	63.4	0.01	31	3.7	3	0.32	30	0.004	174

50 days Ex2	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.69	20	888	78	144	253	30
2	1.70	19	1383	121	541	179	26
3	1.65	19	1753	226	389	287	40
4	1.69	19	2086	447	346	159	33
5	1.70	18	2963	701	393	234	26

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX2.

Sample	e ₁	e ₂	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1											
2											
3											
4											
5											

108 days Ex1	Final dry density g/cm ³	Final water content %	EC 25°C μS/cm (1)	Cl ⁻ ppm (2)	SO ₄ ⁼ ppm (2)	SiO ₂ ppm (3)	Specif. surface BET m ² /g
1	1.66	22	1041	144	122	309	
2	1.71	20	1422	150	319	260	
3	1.71	21	1549	194	352	270	
4	1.67	20	1609	221	350	236	
5	1.65	22	2046	247	644	224	

(1) Electric conductivity of the 1:5 extract, normalized for clay water content.

(2) In the 1:5 extract, normalized for clay water content.

(3) Free silica extracted in Na₂CO₃ 0.5M at room T after 48 hours agitation, normalized for clay water content.

MERCURY POROSIMETRY DATA. EX1. Oven dried.

Sample	e ₁	e ₂	% total	medium φ	% large	Mode large	% medium	Mode medium	% small	Mode small	Uniformity coef.
1	0.675	0.275	41	0.012	20	10	24	0.196	55	0.008	24
2	0.626	0.264	42	0.011	18	6.13	22	0.196	60	0.008	9
3	0.626	0.206	33	0.012	21	6.13	21	0.196	58	0.008	15
4	0.665	0.204	31	0.012	18	6.13	23	0.196	59	0.008	15
5											

ANNEX III

ANNEX III

EQUILIBRIUM IN MEMBRANE CELLS. MONTMORILLONITE. NATURAL INITIAL WATER CONTENT								
Suction MPa	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
2	21	1.65		37.3	41		45	
2	111	1.65		32.3	41		45	
4	112	1.65		31.7	41		45	
6	21	1.65		33.4	41		45	
6	66	1.65		29.2	41		45	
8	21	1.65		31.5	41		45	
8	66	1.65		27.3	41		45	
10	21	1.65		23.3	41		45	
10	66	1.65		25.9	41		45	
10	38	1.65		24.5	37		45	
12	30	1.65		22.8	41		45	
12	123	1.65	1.27	23.8	41	54	45	56
12	85	1.65		23.0	41		45	
12	38	1.75		23.5	37		52	
14	83	1.65		23.3	41		45	
14	123	1.65	1.32	22.7	41	53	45	57
14	77	1.75		23.5	37		52	

One measure per value.

EQUILIBRIUM IN MEMBRANE CELLS. MONTMORILLONITE. INITIAL WATER CONTENT 15%								
Suction MPa	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
2	70	1.65	1.24	31.8	41	55	61	71
4	70	1.65	1.30	28.2	41	53	61	69
6	85	1.65		23.9	41		61	
6	66	1.65		26.0	41		61	
8	64	1.65	1.31	33.8	41	53	61	84
10	65	1.65		25.6	41		61	
10	53	1.65	1.47	22.5	41	47	61	70
12	65	1.65		24.9	41		61	
12	76	1.65	1.49	22.3	41	46	61	72
14	76	1.65	1.49	20.9	41	46	61	67

One measure per value.

EQUILIBRIUM IN MEMBRANE CELLS. MONTMORILLONITE. INITIAL WATER CONTENT 20%								
Suction MPa	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
14	123	1.65	1.52	24.2	41	45	81	81

One measure per value.

EQUILIBRIUM IN SULFURIC ACID ATMOSPHERE. MONTMORILLONITE. INITIAL WATER CONTENT 0%								
Suction MPa	pF	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Final Sr (%)
10.2	5.00	49	1.55		21.8	44		
			1.65		21.6	41		
		52	1.65	1.03	22.1	41	63	36
13.2	5.11	50	1.55		20.2	44		
			1.65	1.11	19.9	41	60	37
18.1	5.25	79	1.65	1.23	17.7	41	56	39
18.5	5.26	51	1.65	1.11	18.7	41	60	35
25.9	5.40	54	1.55		17.4	44		
			1.65	1.15	17.5	41	59	34
44.0	5.63	43	1.55		15.3	44		
			1.65		15.4	41		
		53	1.65	1.20	15.2	41	57	32
58.0	5.75	89	1.65	1.28	14.0	41	54	33
68.0	5.82	89	1.55	1.23	13.3	44	56	29
			1.65	1.28	13.2	41	54	31
75.8	5.87	72	1.65	1.31	12.3	41	53	31
167.5	6.22	92	1.65	1.49	5.9	41	46	19
212.6	6.32	47	1.65	1.51	4.5	41	46	15

Note: All the values are the average of three measures, except * one measure per value.

EQUILIBRIUM IN SULFURIC ACID ATMOSPHERE. MONTMORILLONITE. NATURAL INITIAL WATER CONTENT									
Suction MPa	pF	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
13.9	5.13	108	1.60	1.29	22.6	42	54	41	55
		107	1.65	1.32	22.6	41	53	45	57
		59	1.65	1.35	21.7	41	51	45	57
16.0	5.20	104	1.60	1.34	20.5	42	52	41	53
		103	1.65	1.35	21.1	41	51	45	55
17.8	5.24	108	1.60		20.4	42		41	
		108	1.65	1.41	18.9	41	49	45	54
25.9	5.40	42	1.65	1.42	18.9	41	49	45	55
28.4	5.45	42	1.65	1.44	18.1	41	48	45	54
33.0	5.51	192	*1.55	1.37	19.3	44	51	39	52
			*1.65	1.39	19.3	41	50	45	54
			*1.75	1.47	19.3	37	47	52	60
			*1.85	1.51	19.3	33	46	61	64
			*1.95	1.55	19.3	30	44	72	68
44.4	5.64	57	1.90	1.61	17.0	32	42	66	65
58.0	5.75	194	1.65	1.48	17.1	41	47	45	54
			1.75	1.56	17.0	37	44	52	60
79.9	5.89	55	1.9	1.72	14.3	32	38	66	65

Note: All the values are the average of three measures, except * one measure per value.

EQUILIBRIUM IN SULFURIC ACID ATMOSPHERE. MONTMORILLONITE. NATURAL INITIAL WATER CONTENT									
Suction MPa	pF	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
82.4	5.91	71	1.60	1.54	13.1	42	45	41	45
			1.65	1.60	13.0	41	42	45	49
98.7	5.93	189	1.65		15.4	41		45	
			1.75		15.4	37		52	
125.1	6.09	77	1.60		10.5	42		41	
			1.65		10.1	41		45	
128.8	6.10	108	*1.55		11.6	44		39	
		77	1.60		10.4	42		41	
		108	*1.65		11.6	41		45	
		77	1.65		10.3	41		45	
		108	*1.75		11.6	37		52	
		108	*1.85		11.7	33		61	
		108	*1.95		11.7	30		72	
137.6	6.13	51	1.40	1.44	10.2	50	48	31	30
		51	1.90	1.90	10.9	32	32	66	65
161.1	6.20	39	1.65	1.67	10.6	41	40	45	44
191.6	6.27	108	*1.55		9.3	44		39	
		63	1.60		8.1	42		41	
		108	*1.65		9.3	41		45	
		63	1.65		8.1	41		45	
		108	*1.75		9.3	37		52	
		108	*1.85		9.4	33		61	
289.3	6.45	100	*1.55		6.2	44		39	
		59	1.60		5.3	42		41	
		100	*1.65		6.2	41		45	
		59	1.65		5.4	41		45	
		100	*1.75		6.2	37		52	
		100	*1.85		6.2	33		61	
		100	*1.95		6.7	30		72	
385.3	6.58	58	1.60		3.6	42		41	
			1.65		3.6	41		45	

Note: All the values are the average of three measures, except * one measure per value.

EQUILIBRIUM IN SULFURIC ACID ATMOSPHERE. MONTMORILLONITE. INITIAL WATER CONTENT 15%									
Suction MPa	pF	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
13.9	5.13	107	1.60	1.37	23.3	42	51	57	63
			1.65	1.40	22.8	41	50	61	64
16.0	5.20	104	1.60	1.41	20.5	42	49	57	59
		103	1.65	1.43	21.4	41	49	61	63
		59	1.65	1.54	21.2	41	45	61	73
17.8	5.24	108	1.60	1.42	19.9	42	49	57	53
			1.65	1.49	19.9	41	46	61	64
25.9	5.40	42	1.65	1.56	18.9	41	44	61	67
28.4	5.45	42	1.65	1.56	18.2	41	44	61	65
33.0	5.51	192	*1.55	1.46	20.0	44	47	53	61
			*1.65	1.55	20.0	41	44	61	70
			*1.75	1.60	20.0	37	42	71	75
			*1.85	1.69	20.0	33	39	83	86
			*1.95	1.68	20.0	30	39	98	85
58.0	5.75	194	1.65	1.62	17.9	41	42	61	69
			1.75	1.69	17.8	37	39	71	77
58.0	5.75	71	1.65	1.64	16.0	41	41	61	64
74.8	5.87	57	1.65	1.69	14.1	41	39	61	61

Note: All the values are the average of three measures, except * one measure per value.

EQUILIBRIUM IN SULFURIC ACID ATMOSPHERE. MONTMORILLONITE. INITIAL WATER CONTENT 15%									
Suction MPa	pF	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
82.4	5.91	71	1.60	1.69	13.7	42	39	57	59
			1.65	1.75	13.1	41	37	61	62
98.7	5.93	189	1.65		16.0	41		61	
			1.75		16.0	37		71	
104.3	6.01	58	1.65	1.71	13.0	41	38	61	58
125.1	6.09	77	1.60		10.8	42		57	
			1.65		10.2	41		61	
128.8	6.10	77	1.60		11.5	42		57	
			1.65		11.1	41		61	
161.1	6.20	39	1.65	1.73	10.7	41	38	61	49
191.6	6.27	63	1.60		8.3	42		57	
			1.65		9.4	41		61	
289.3	6.45	59	1.60		6.2	42		57	
			1.65		5.9	41		61	
385.3	6.58	58	1.60		4.2	42		57	
			1.65		4.6	41		61	

Note: All the values are the average of three measures, except * one measure per value.

EQUILIBRIUM IN SULFURIC ACID ATMOSPHERE. MONTMORILLONITE. INITIAL WATER CONTENT 20%									
Suction MPa	pF	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
13.9	5.13	107	1.60	1.47	22.9	42	47	75	71
		107	1.65	1.51	23.7	41	46	81	78
		59	1.65	1.76	21.6	41	37	81	104
16.0	5.20	104	1.60	1.51	20.9	42	46	75	69
		103	1.65	1.57	22.1	41	44	81	80
17.8	5.24	108	1.60	1.55	20.1	42	44	75	70
			1.65	1.49	19.7	41	46	81	63
25.9	5.40	42	1.65	1.69	19.6	41	39	81	84
28.4	5.45	42	1.65	1.71	19.4	41	38	81	86
44.0	5.63	53	1.65	1.73	18.0	41	38	81	83
49.5	5.69	43	1.65	1.71	18.0	41	38	81	80
66.4	5.81	97	1.65	1.79	16.4	41	36	81	82
74.8	5.87	57	1.65	1.79	15.5	41	36	81	78
82.4	5.91	71	1.60		14.6	42		75	
			1.65		13.8	41		81	
104.3	6.01	58	1.65	1.78	13.9	41	36	81	69
125.1	6.09	77	1.60		11.4	42		75	
			1.65		10.8	41		81	

Note: All the values are the average of three measures, except * one measure per value.

EQUILIBRIUM IN SULFURIC ACID ATMOSPHERE. MONTMORILLONITE. NATURAL INITIAL WATER CONTENT									
Suction MPa	pF	Stabilization days	Initial dry density (g/cm ³)	Final dry density (g/cm ³)	Final w (%)	Initial n (%)	Final n (%)	Initial Sr (%)	Final Sr (%)
128.8	6.10	77	1.60		12.1	42		75	
			1.65		11.1	41		81	
161.1	6.20	39	1.65	1.79	11.1	41	36	81	56
191.6	6.27	63	1.60		8.7	42		75	
		60	1.65		8.6	41		81	
289.3	6.45	59	1.60		6.6	42		75	
			1.65		6.1	41		81	
385.3	6.58	58	1.60		4.8	42		75	
			1.65		4.3	41		81	

Note: All the values are the average of three measures, except * one measure per value.

FOURTH QUARTER 2010 AIR QUALITY MONITORING RESULTS IN THE WATER COURSE									
Station	PM ₁₀ (µg/m ³)	PM _{2.5} (µg/m ³)	NO ₂ (ppb)	NO _x (ppb)	O ₃ (ppb)	CO (ppm)	SO ₂ (ppb)	Temperature (°C)	Humidity (%)
1	12.5	5.2	15.1	22.3	45.6	0.8	1.2	15.2	65.1
2	11.8	4.9	14.5	21.7	44.8	0.7	1.1	14.8	64.5
3	13.2	5.5	16.0	23.1	46.2	0.9	1.3	15.5	65.8
4	12.1	5.0	15.3	22.5	45.9	0.8	1.2	15.0	64.9
5	11.5	4.8	14.8	21.9	44.5	0.7	1.1	14.9	64.2
6	12.8	5.3	15.8	22.8	46.0	0.8	1.2	15.3	65.5
7	11.9	4.9	14.6	21.8	44.9	0.7	1.1	14.9	64.6
8	13.0	5.4	15.9	23.0	46.1	0.9	1.3	15.4	65.7
9	12.3	5.1	15.4	22.6	45.7	0.8	1.2	15.1	65.0
10	11.7	4.8	14.7	21.6	44.6	0.7	1.1	14.8	64.4
11	12.6	5.2	15.6	22.9	45.8	0.8	1.2	15.2	65.3
12	12.0	5.0	15.2	22.4	45.6	0.8	1.2	15.0	64.8
13	11.4	4.7	14.4	21.4	44.4	0.7	1.1	14.7	64.1
14	12.9	5.3	15.9	23.2	46.3	0.9	1.3	15.6	65.9
15	12.2	5.1	15.5	22.7	45.9	0.8	1.2	15.1	65.0
16	11.6	4.8	14.9	21.7	44.7	0.7	1.1	14.8	64.3
17	12.7	5.2	15.7	23.0	46.0	0.8	1.2	15.3	65.4
18	12.1	5.0	15.3	22.5	45.7	0.8	1.2	15.0	64.9
19	11.5	4.8	14.8	21.9	44.5	0.7	1.1	14.9	64.2
20	12.8	5.3	15.8	22.8	46.0	0.8	1.2	15.3	65.5
21	11.9	4.9	14.6	21.8	44.9	0.7	1.1	14.9	64.6
22	13.0	5.4	15.9	23.0	46.1	0.9	1.3	15.4	65.7
23	12.3	5.1	15.4	22.6	45.7	0.8	1.2	15.1	65.0
24	11.7	4.8	14.7	21.6	44.6	0.7	1.1	14.8	64.4
25	12.6	5.2	15.6	22.9	45.8	0.8	1.2	15.2	65.3
26	12.0	5.0	15.2	22.4	45.6	0.8	1.2	15.0	64.8
27	11.4	4.7	14.4	21.4	44.4	0.7	1.1	14.7	64.1
28	12.9	5.3	15.9	23.2	46.3	0.9	1.3	15.6	65.9
29	12.2	5.1	15.5	22.7	45.9	0.8	1.2	15.1	65.0
30	11.6	4.8	14.9	21.7	44.7	0.7	1.1	14.8	64.3
31	12.7	5.2	15.7	23.0	46.0	0.8	1.2	15.3	65.4
32	12.1	5.0	15.3	22.5	45.7	0.8	1.2	15.0	64.9
33	11.5	4.8	14.8	21.9	44.5	0.7	1.1	14.9	64.2
34	12.8	5.3	15.8	22.8	46.0	0.8	1.2	15.3	65.5
35	11.9	4.9	14.6	21.8	44.9	0.7	1.1	14.9	64.6
36	13.0	5.4	15.9	23.0	46.1	0.9	1.3	15.4	65.7
37	12.3	5.1	15.4	22.6	45.7	0.8	1.2	15.1	65.0
38	11.7	4.8	14.7	21.6	44.6	0.7	1.1	14.8	64.4
39	12.6	5.2	15.6	22.9	45.8	0.8	1.2	15.2	65.3
40	12.0	5.0	15.2	22.4	45.6	0.8	1.2	15.0	64.8
41	11.4	4.7	14.4	21.4	44.4	0.7	1.1	14.7	64.1
42	12.9	5.3	15.9	23.2	46.3	0.9	1.3	15.6	65.9
43	12.2	5.1	15.5	22.7	45.9	0.8	1.2	15.1	65.0
44	11.6	4.8	14.9	21.7	44.7	0.7	1.1	14.8	64.3
45	12.7	5.2	15.7	23.0	46.0	0.8	1.2	15.3	65.4
46	12.1	5.0	15.3	22.5	45.7	0.8	1.2	15.0	64.9
47	11.5	4.8	14.8	21.9	44.5	0.7	1.1	14.9	64.2
48	12.8	5.3	15.8	22.8	46.0	0.8	1.2	15.3	65.5
49	11.9	4.9	14.6	21.8	44.9	0.7	1.1	14.9	64.6
50	13.0	5.4	15.9	23.0	46.1	0.9	1.3	15.4	65.7

Note: All the values are the average of three measures, except * one measure per value.

ANNEX IV

ANNEX IV

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN1_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	3-7-92	End:	4-11-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

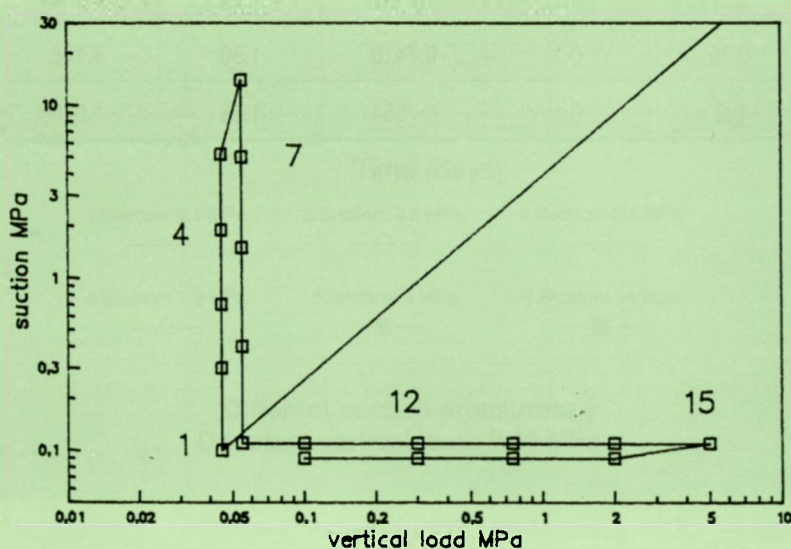
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.8 g	Assumed dry weight:	18.47 g
Water content:	12.6	Dry density:	1.60 g/cm ³

Final data

Weight:	25.47 g	Dry weight:	18.3 g
Water content:	39.2%	Initial dry density:	1.59 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.712 cm	Volume 1:	13.71 cm ³
		Dry dens. 1:	1.33 g/cm ³
Final h (deformation gauge:)	0.765 cm	Volume 2:	14.72 cm ³
		Dry dens. 2:	1.24 g/cm ³

Stress path:

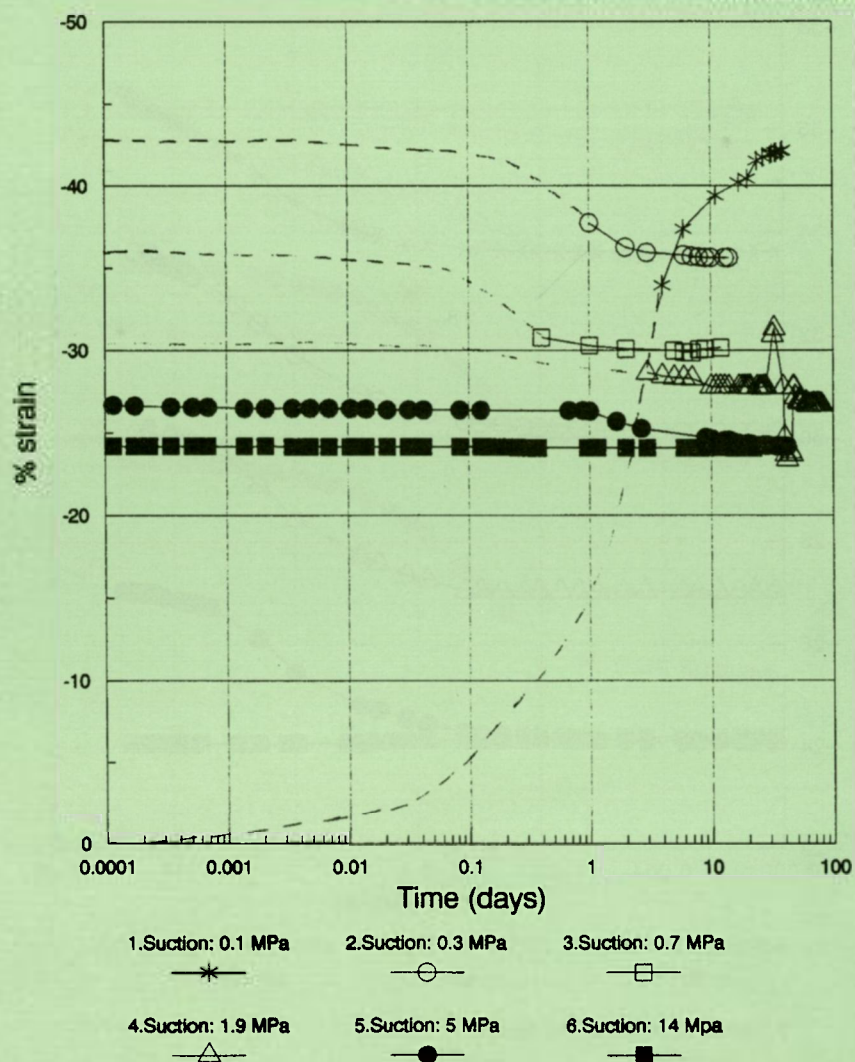


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN1_1

# Step	Vert. load MPa	Suction MPa	Final height h	Dry density	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.05	0.1	0.8529	1.13	1.470	59.5
2	0.05	0.3	0.8137	1.18	1.356	57.6
3	0.05	0.7	0.7803	1.23	1.259	55.7
4	0.05	1.9	0.7600	1.26	1.201	54.6
5	0.05	5.2	0.7450	1.29	1.157	53.6
6	0.05	14.0	0.7444	1.29	1.555	53.6
7	0.05	5.0	0.7622	1.26	1.207	54.7
8	0.05	1.5	0.7807	1.23	1.260	55.8
9	0.05	0.4	0.8017	1.20	1.321	56.9
10	0.05	0.1	0.8206	1.17	1.376	57.0
11	0.1	0.1	0.8217	1.17	1.379	58.0
12	0.3	0.1	0.8119	1.18	1.351	57.5
13	0.75	0.1	0.7872	1.22	1.279	56.1
14	2.0	0.1	0.7440	1.29	1.154	53.6
15	5.0	0.1	0.6962	1.38	1.016	50.4
16	2.0	0.1	0.7137	1.35	1.066	51.6
17	0.75	0.1	0.7410	1.30	1.146	53.4
18	0.3	0.1	0.7654	1.25	1.216	54.9

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN1_1

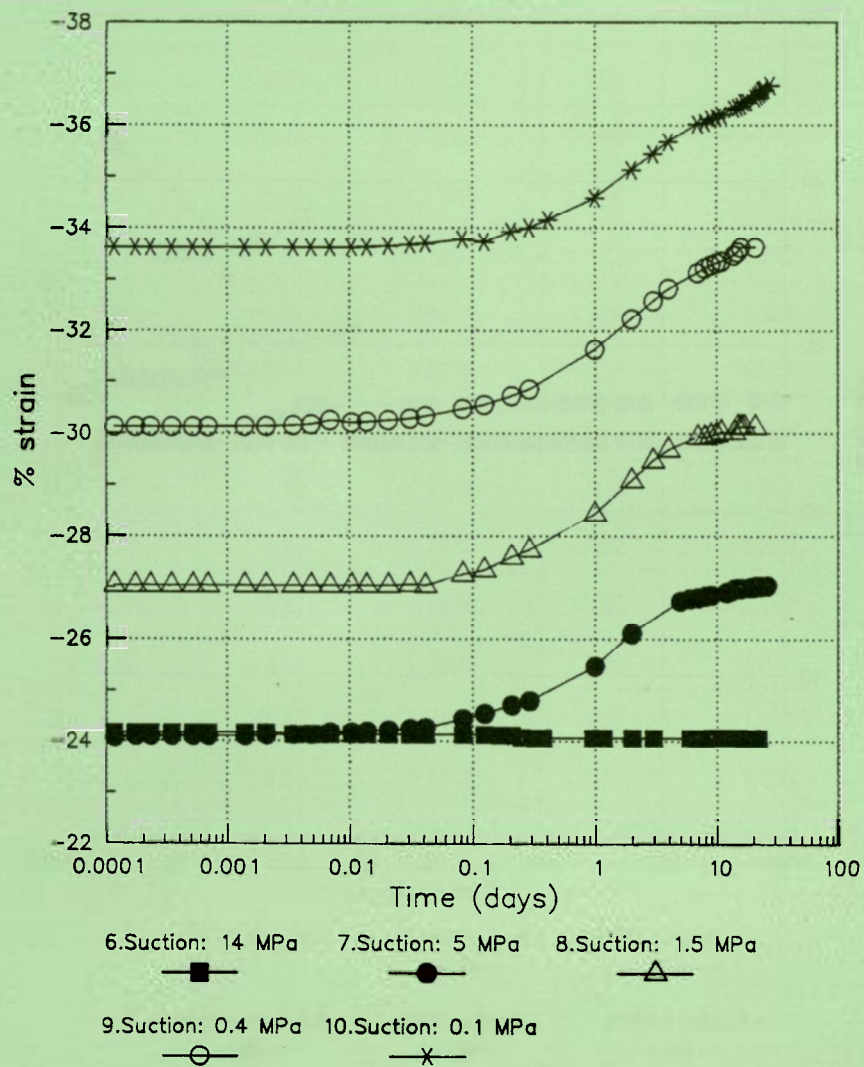
Initial dry density and w : 1.6 g/cm^3 , 12.2%



Different suction pressures.
 Constant vertical load: 0.05 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN1_1

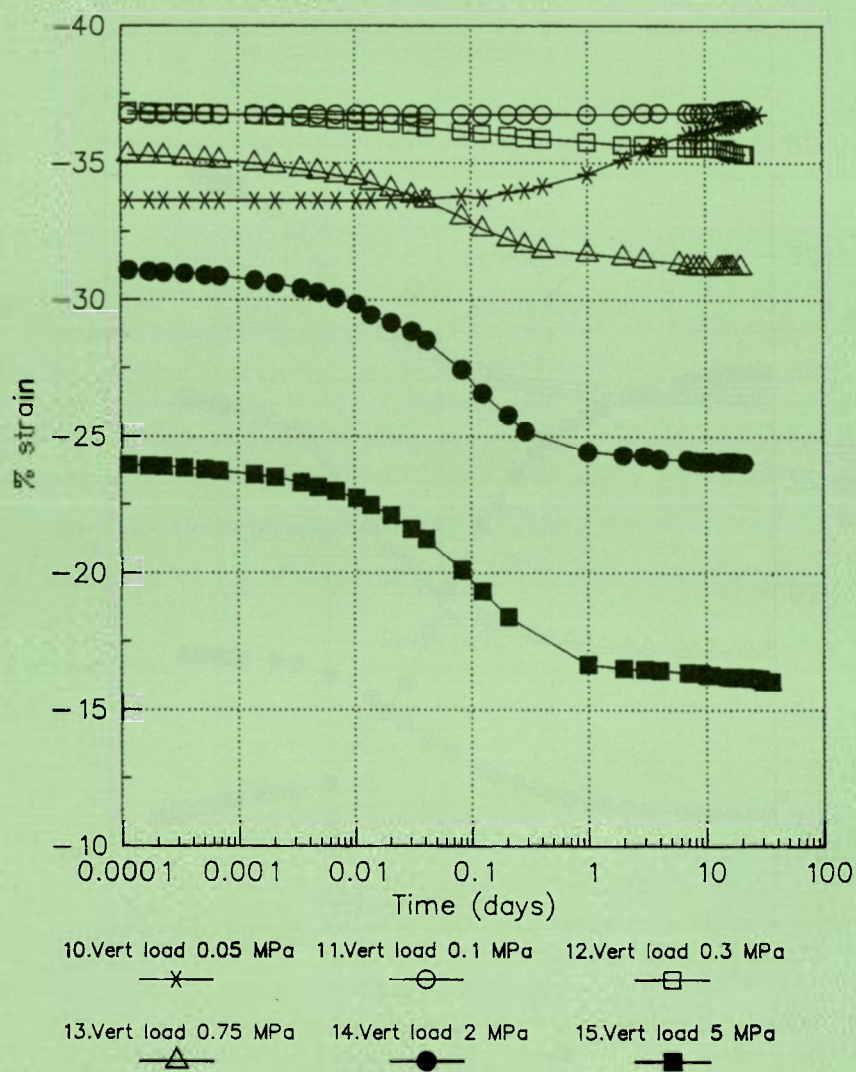
Initial dry density and w : 1.6 g/cm³, 12.2%



Different suction pressures.
Constant vertical load: 0.05 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN1_1

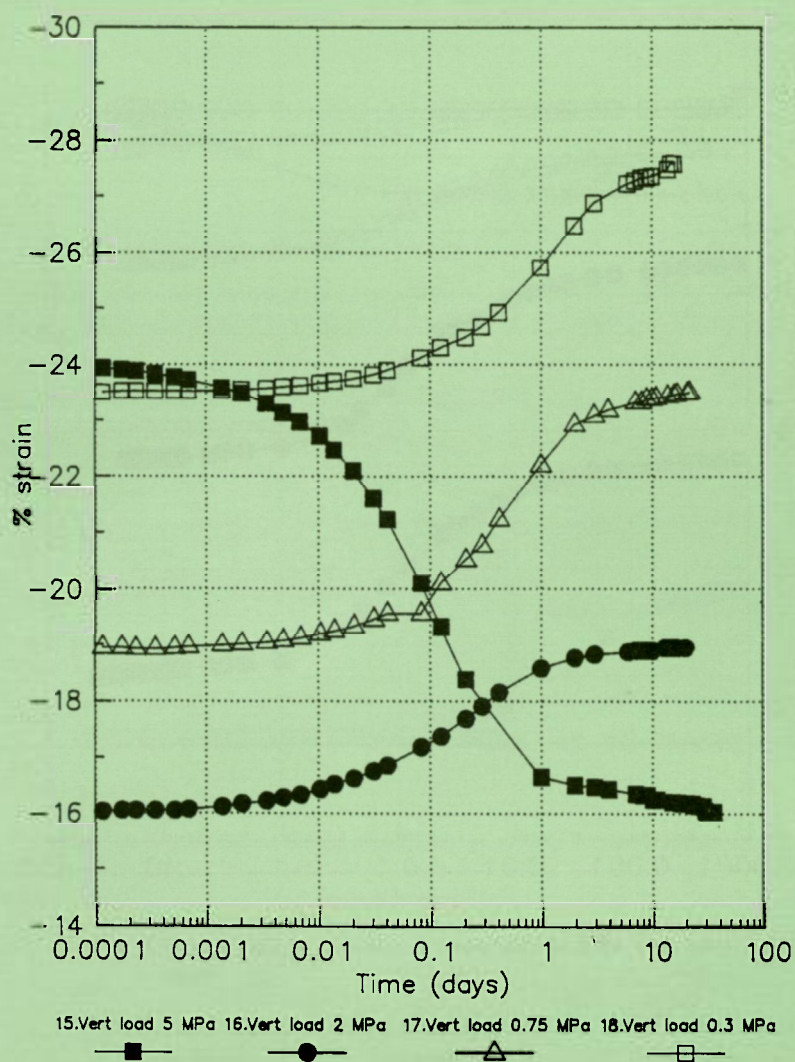
Initial dry density and w : 1.6 g/cm³, 12.2%



Loading at constant suction 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN1_1

Initial dry density and w: 1.6 g/cm³, 12.2%



Unloading at constant suction 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN2_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	3-7-92	End:	4-11-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

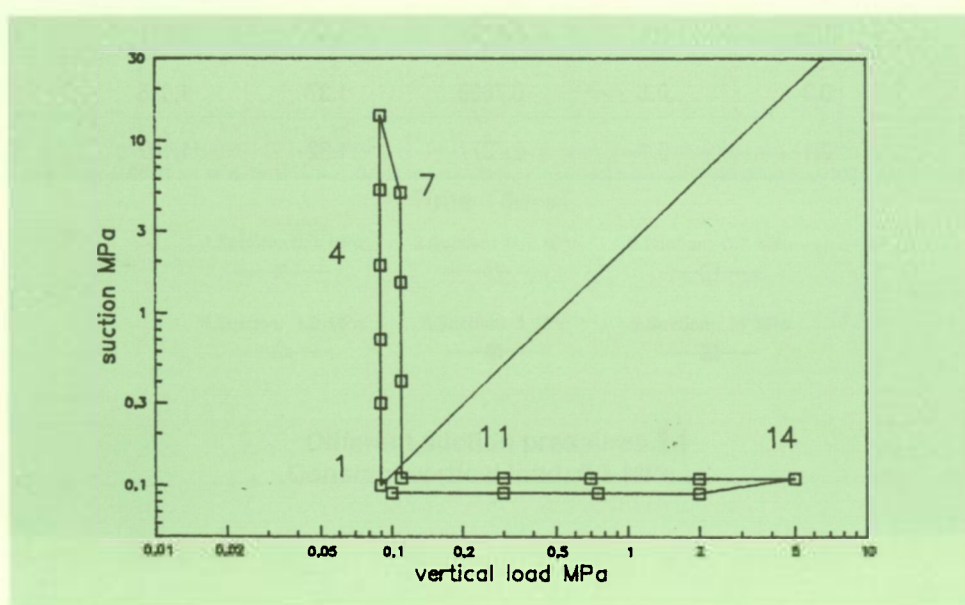
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.8 g	Assumed dry weight:	18.47 g
Water content:	12.6	Dry density:	1.60 g/cm ³

Final data

Weight:	26.12 g	Dry weight:	18.37 g
Water content:	41.4%	Initial dry density:	1.59 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.733 cm	Volume 1:	14.10 cm ³
		Dry dens. 1:	1.30 g/cm ³
Final h (deformation gauge:)	0.728 cm	Volume 2:	14.01 cm ³
		Dry dens. 2:	1.31 g/cm ³

Stress path:

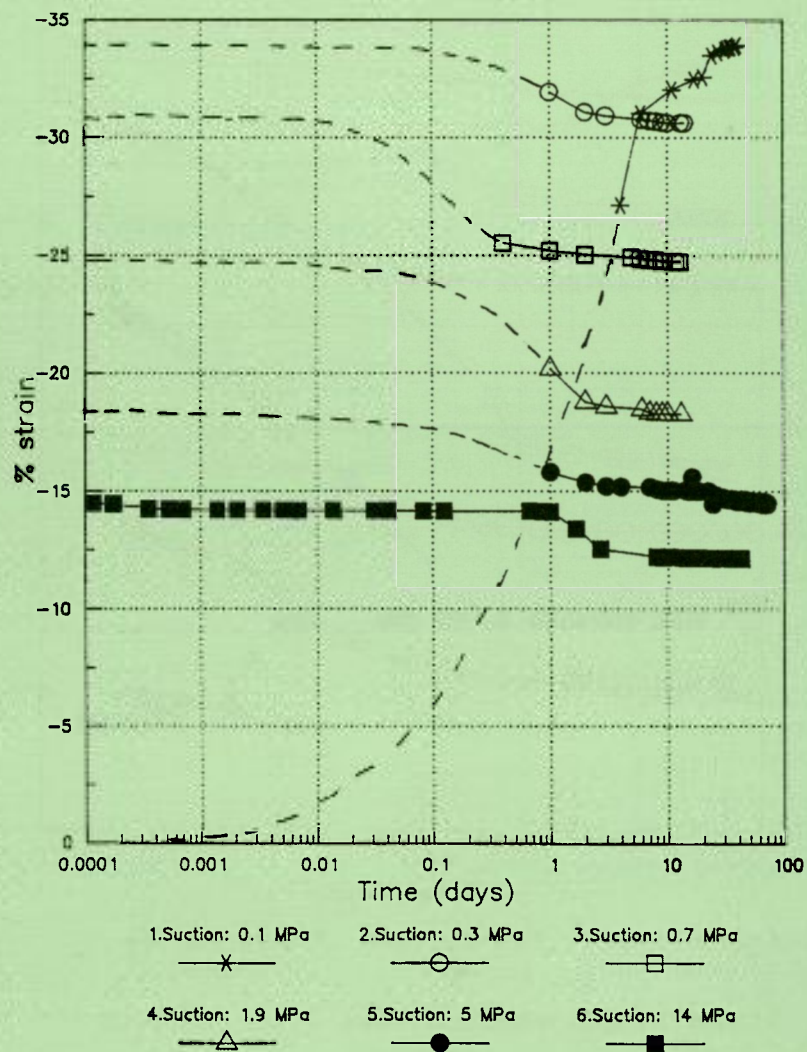


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN2_1

# Step	Vert. load MPa	Suction MPa	Final height h	Dry density	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.1	0.1	0.8035	1.19	1.326	57.0
2	0.1	0.3	0.7838	1.22	1.269	55.9
3	0.1	0.7	0.7485	1.28	1.167	53.9
4	0.1	1.9	0.7096	1.35	1.055	51.3
5	0.1	5.2	0.6869	1.40	0.989	49.7
6	0.1	14.0	0.6728	1.43	0.948	48.7
7	0.1	5.0	0.6761	1.42	0.958	48.9
8	0.1	1.5	0.6956	1.38	1.014	50.4
9	0.1	0.4	0.7245	1.33	1.098	52.3
10	0.1	0.1	0.7438	1.29	1.154	53.6
11	0.3	0.1	0.7359	1.30	1.131	53.1
12	0.7	0.1	0.7141	1.34	1.068	51.6
13	2.0	0.1	0.6672	1.44	0.932	48.2
14	5.0	0.1	0.6285	1.53	0.820	45.0
15	2.0	0.1	0.6496	1.48	0.881	46.8
16	0.75	0.1	0.6783	1.42	0.964	49.1
17	0.3	0.1	0.7029	1.37	1.035	50.9
18	0.1	0.1	0.7277	1.32	1.107	52.5

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN2_1

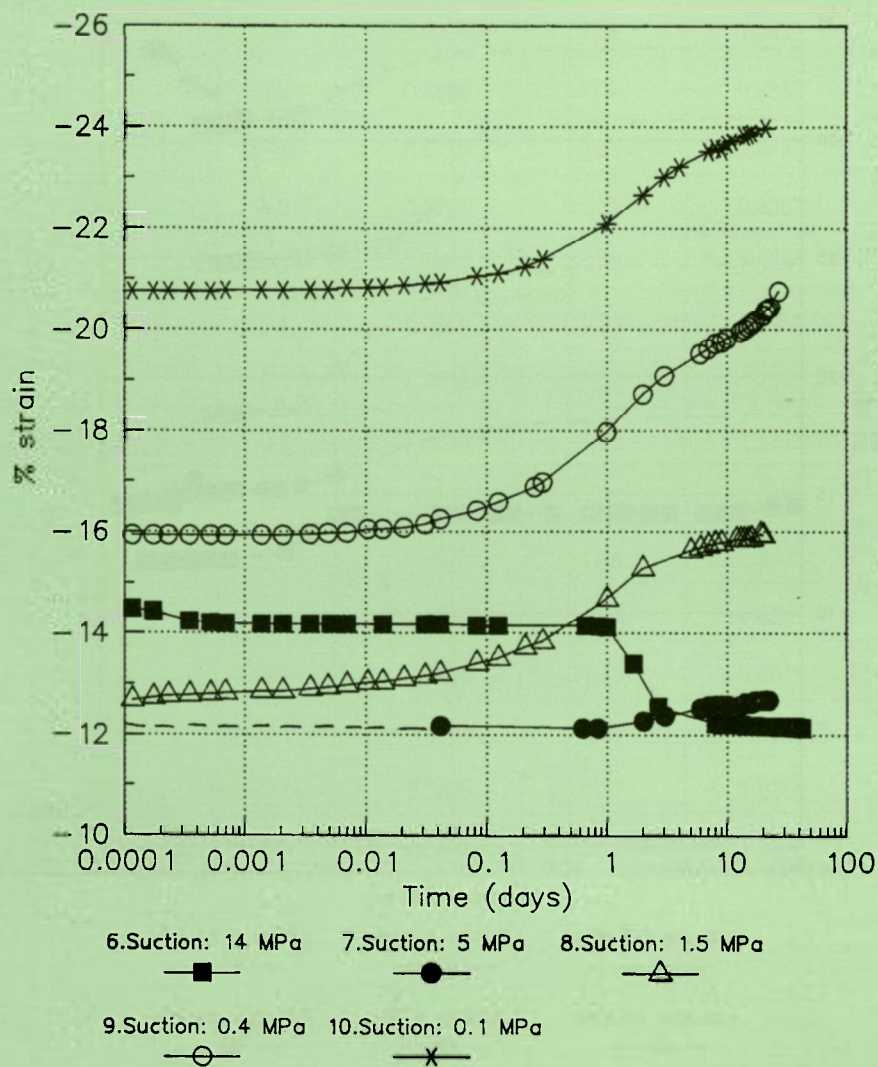
Initial dry density and w : 1.6 g/cm^3 , 12.2%



Different suction pressures.
Constant vertical load: 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN2_1

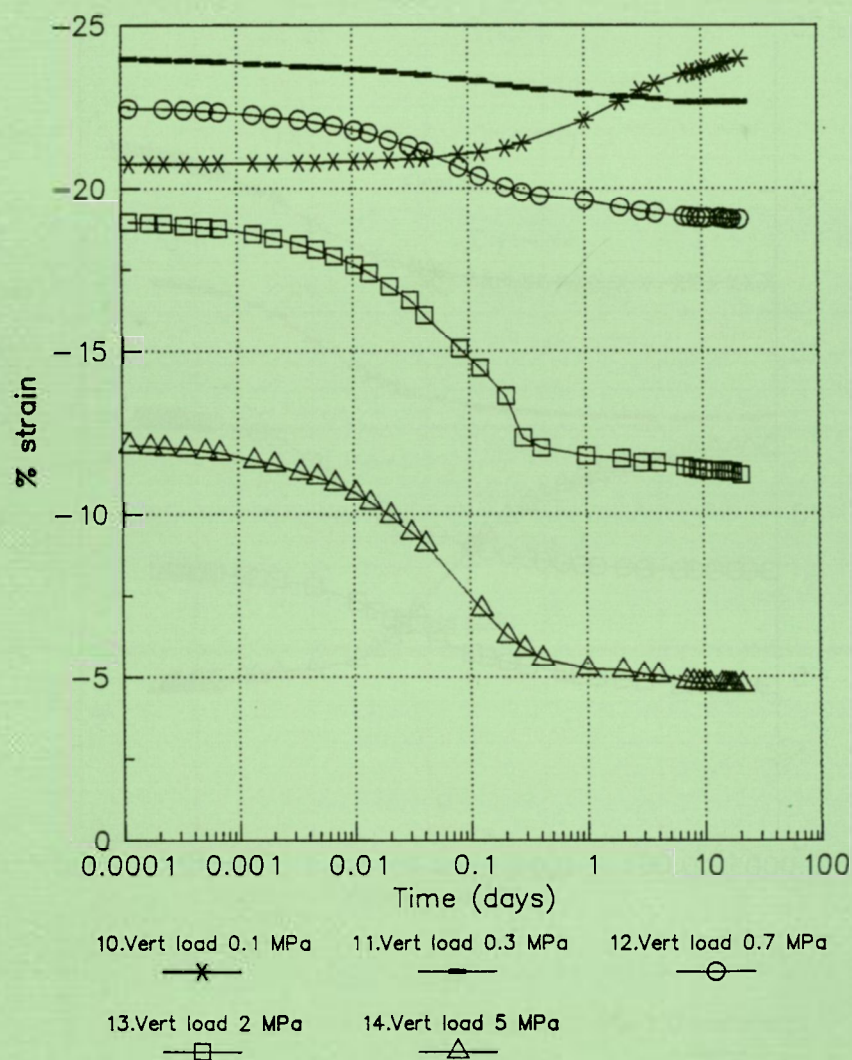
Initial dry density and w : 1.6 g/cm³, 12.2%



Different suction pressures.
Constant vertical load: 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN2_1

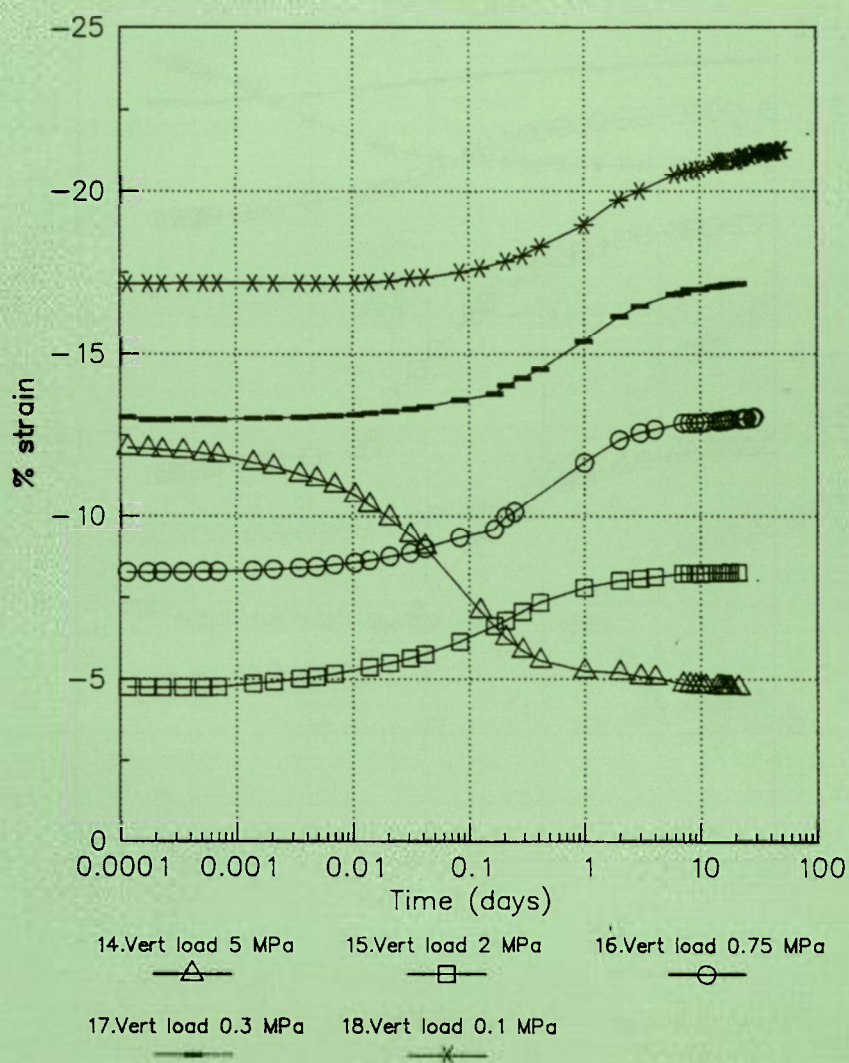
Initial dry density and w : 1.6 g/cm³, 12.2%



Loading at constant suction pressure 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN2_1

Initial dry density and w: 1.6 g/cm³, 12.2%



Unloading at constant suction pressure 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN3_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	12-8-92	End:	20-12-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

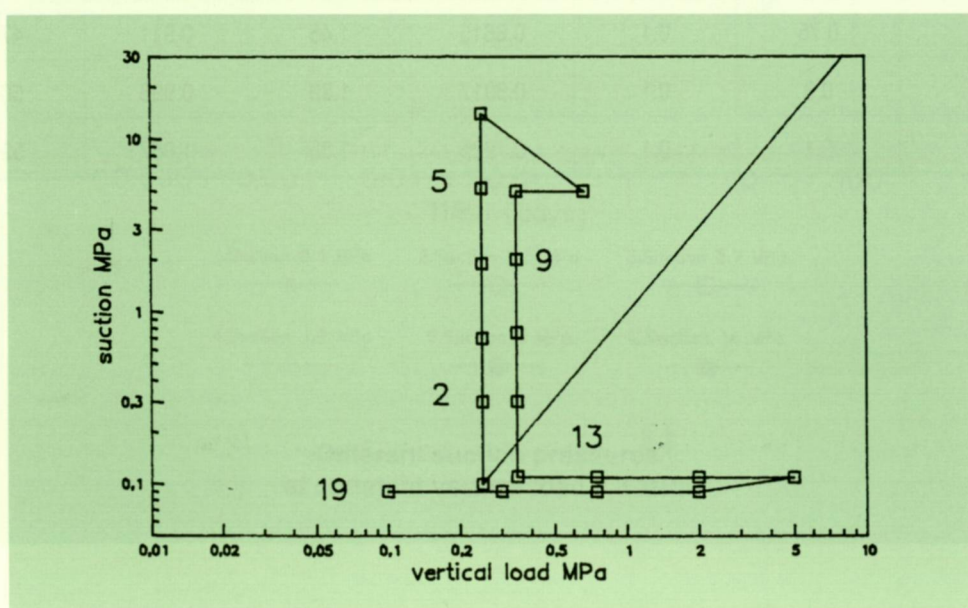
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.7 g	Assumed dry weight:	18.51 g
Water content:	11.8	Dry density:	1.60 g/cm ³

Final data

Weight:	26.63 g	Dry weight:	18.67 g
Water content:	42.6%	Initial dry density:	1.62 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.730 cm	Volume 1:	14.04 cm ³
		Dry dens. 1:	1.33 g/cm ³
Final h (deformation gauge:)	0.722 cm	Volume 2:	13.89 cm ³
		Dry dens. 2:	1.34 g/cm ³

Stress path:

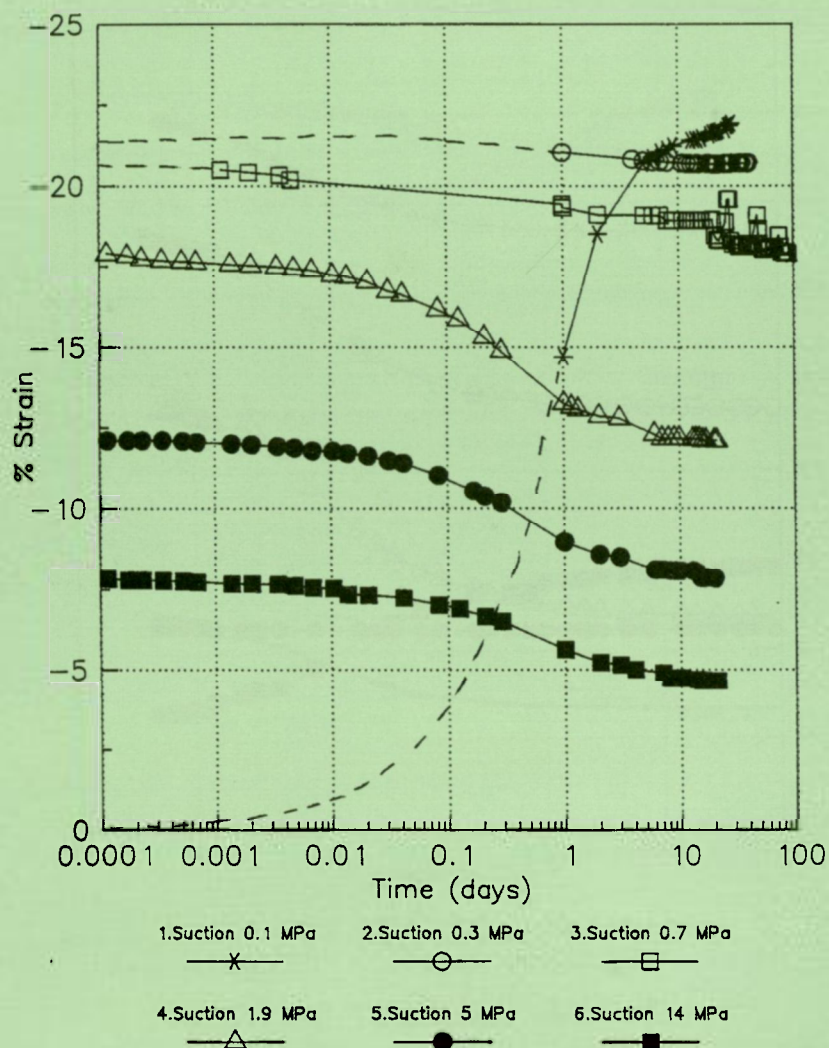


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN3_1

# Step	Vert. load MPa	Suction MPa	Final height h	Dry density	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.3	0.1	0.7316	1.32	1.113	52.7
2	0.3	0.3	0.7243	1.33	1.092	52.2
3	0.3	0.7	0.7074	1.36	1.044	51.1
4	0.3	1.9	0.6726	1.43	0.943	48.5
5	0.3	5.2	0.6470	1.49	0.869	46.5
6	0.3	14.0	0.6279	1.53	0.814	44.9
7'	0.7	5.0	0.6387	1.51	0.845	45.8
7	0.3	5.0	0.6400	1.50	0.849	45.9
8	0.3	1.5	0.6683	1.44	0.931	48.2
9	0.3	0.4	0.6920	1.39	0.999	50.0
10	0.3	0.1	0.7074	1.36	1.044	51.1
11	0.75	0.1	0.6997	1.38	1.021	50.5
12	2.0	0.1	0.6657	1.45	0.923	48.0
13	5.0	0.1	0.6177	1.56	0.784	44.0
14	2.0	0.1	0.6326	1.52	0.827	45.3
15	0.75	0.1	0.6615	1.45	0.911	47.7
16	0.3	0.1	0.6917	1.39	0.998	50.0
17	0.1	0.1	0.7225	1.33	1.087	52.1

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN3_1

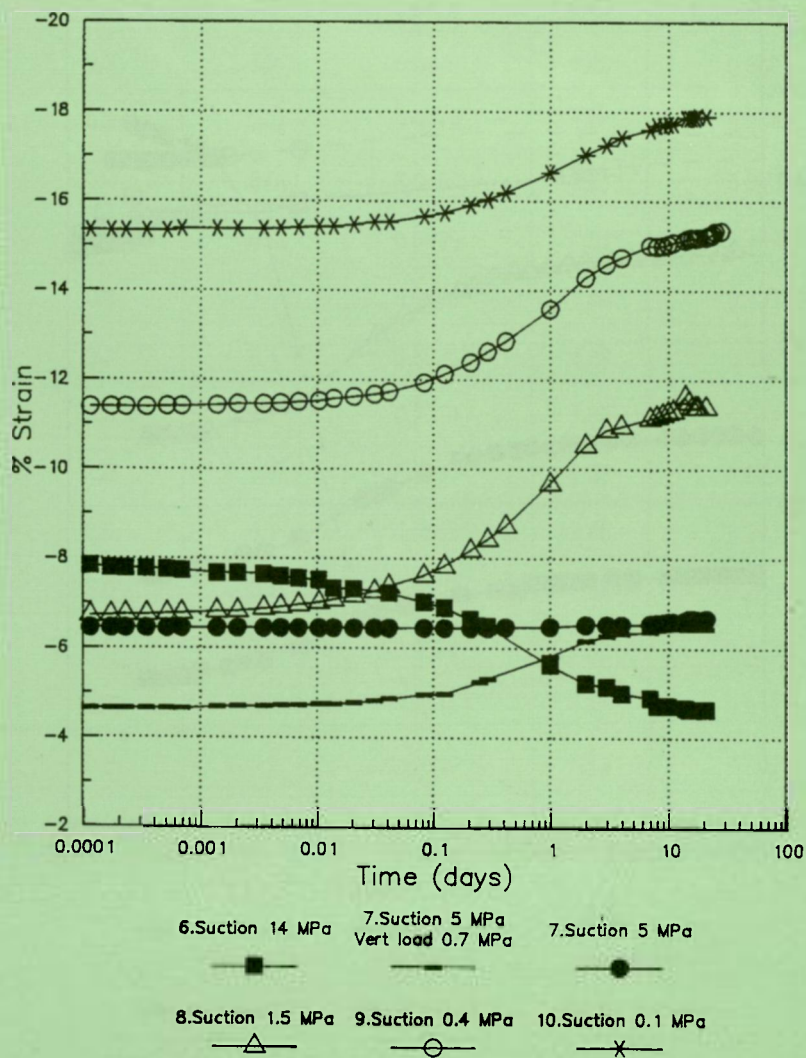
Initial dry density and w : 1.6 g/cm³, 12.2%



Different suction pressures
at constant vertical load 0.3 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN3_1

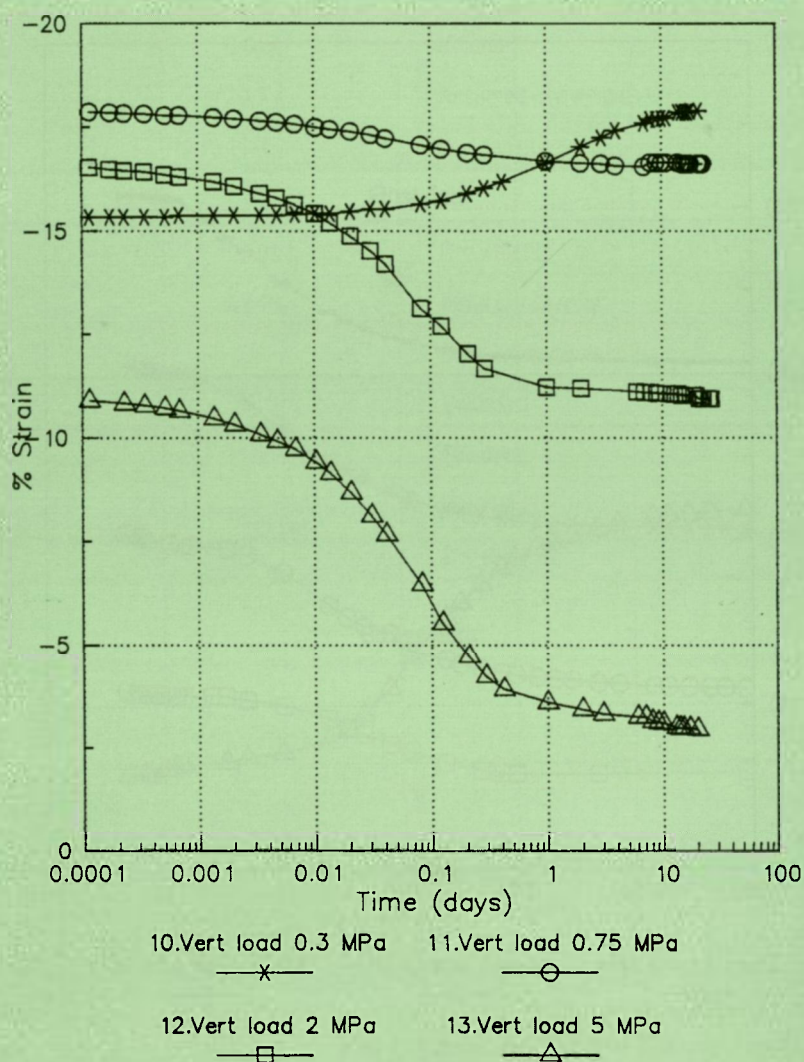
Initial dry density and w : 1.6 g/cm^3 , 12.2%



Different suction pressures
at constant vertical load 0.3 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN3_1

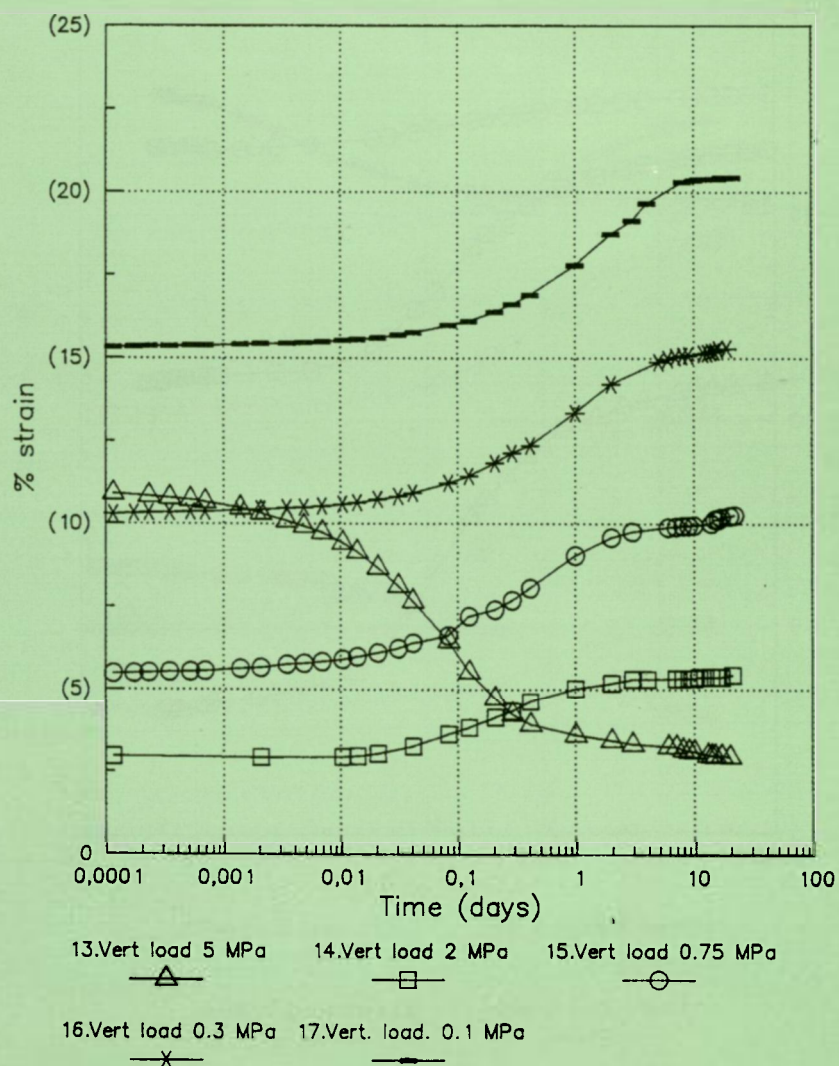
Initial dry density and w : 1.6 g/cm³, 12.2%



Loading at constant suction pressure 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN3_1

Initial dry density 1.6 g/cm^3 , initial w 11.8%



Unloading at constant suction pressure 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN4_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	13-8-92	End:	2-11-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

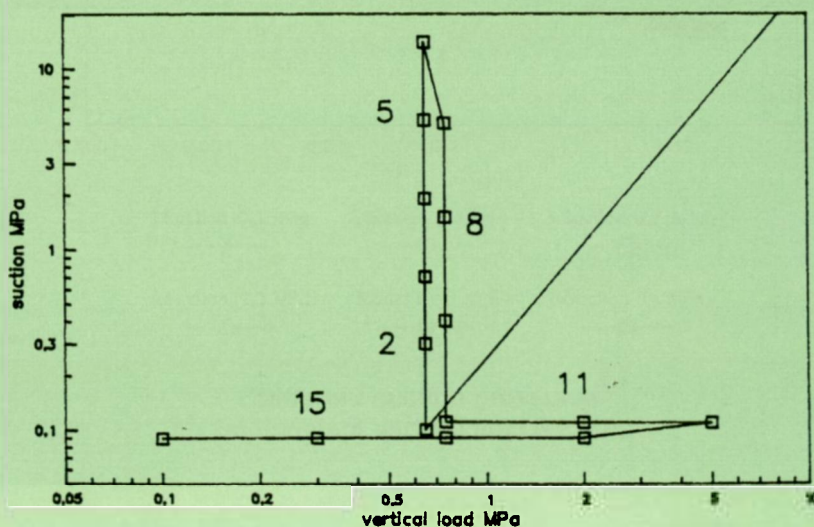
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.7 g	Assumed dry weight:	18.51 g
Water content:	11.8	Dry density:	1.60 g/cm ³

Final data

Weight:	25.96 g	Dry weight:	18.14 g
Water content:	43.1%	Initial dry density:	1.57 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	7.3 cm	Volume 1:	14.04 cm ³
		Dry dens. 1:	1.29 g/cm ³
Final h (deformation gauge:)	7.08 cm	Volume 2:	13.62 cm ³
		Dry dens. 2:	1.33 g/cm ³

Stress path:

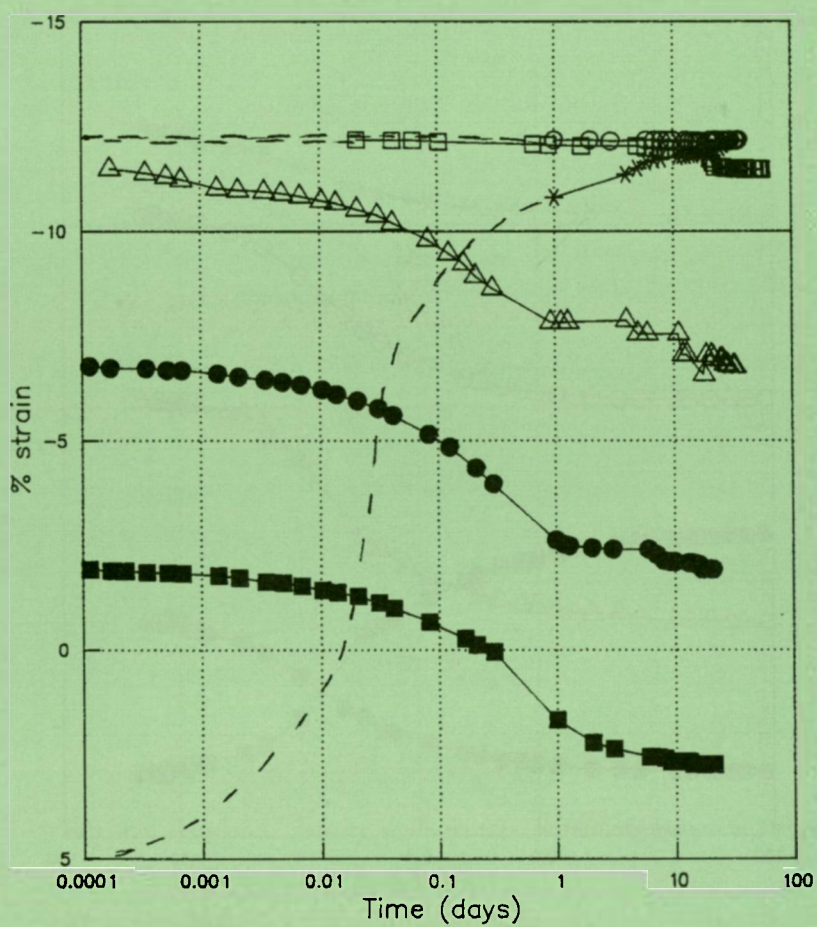


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN4_1

# Step	Vert. load MPa	Suction MPa	Final height h	Dry density	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.7	0.1	0.6730	1.43	0.944	48.6
2	0.7	0.3	0.6731	1.43	0.944	48.6
3	0.7	0.7	0.6689	1.44	0.932	48.2
4	0.7	1.9	0.6406	1.50	0.851	46.0
5	0.7	5.2	0.6115	1.57	0.766	43.4
6	0.7	14.0	0.5835	1.65	0.686	40.7
7	0.7	5.0	0.6011	1.60	0.736	42.4
8	0.7	1.5	0.6274	1.53	0.812	44.8
9	0.7	0.4	0.6489	1.48	0.875	46.7
10	0.7	0.1	0.6596	1.46	0.905	47.5
11	2.0	0.1	0.6429	1.50	0.857	46.2
12	5.0	0.1	0.6069	1.59	0.753	43.0
13	2.0	0.1	0.6248	1.54	0.805	44.6
14	0.75	0.1	0.6504	1.48	0.879	46.8
15	0.3	0.1	0.6768	1.42	0.955	48.9
16	0.1	0.1	0.7081	1.36	1.046	51.1

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN4_1

Initial dry density 1.6 g/cm^3 , initial w 12%

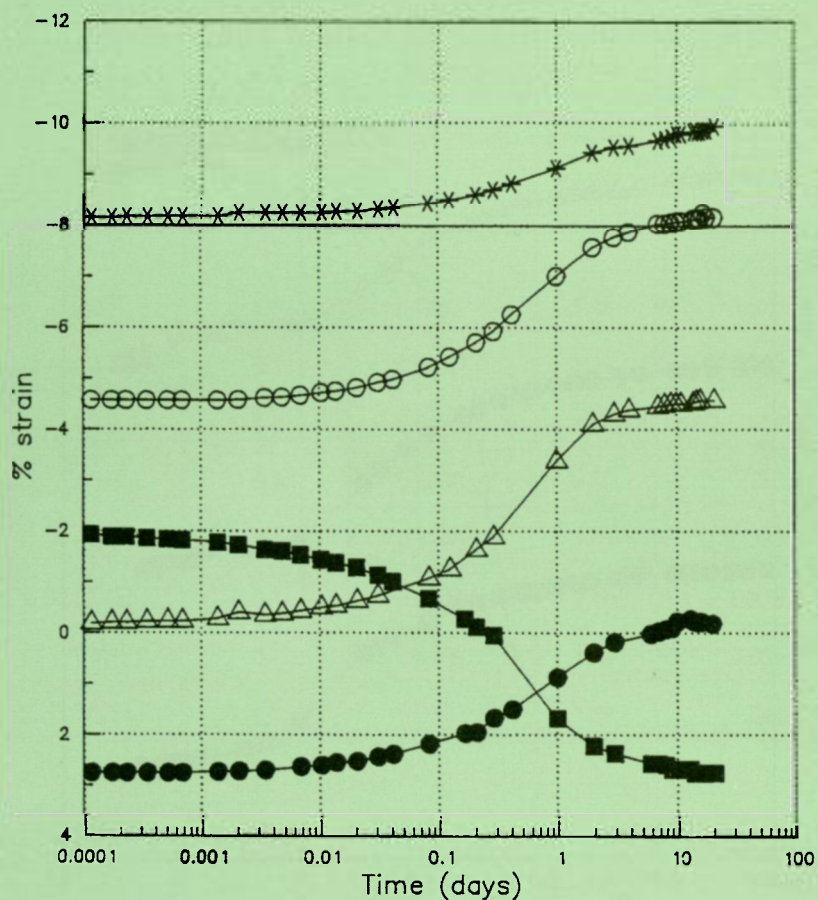


- | | | |
|--------------------|--------------------|--------------------|
| 1. Suction 0.1 MPa | 2. Suction 0.3 MPa | 3. Suction 0.7 MPa |
| — x — | — ○ — | — □ — |
| 4. Suction 1.9 MPa | 5. Suction 5 MPa | 6. Suction 14 MPa |
| — △ — | — ● — | — ■ — |

Different suction pressures
at constant vertical load 0.7 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN4_1

Initial dry density 1.6 g/cm³, initial w 11,8%



6.Suction 14 MPa 7.Suction 5 MPa 8.Suction 1.5 MPa

—■—

—●—

—△—

9.Suction 0.4 MPa 10.Suction 0.1 MPa

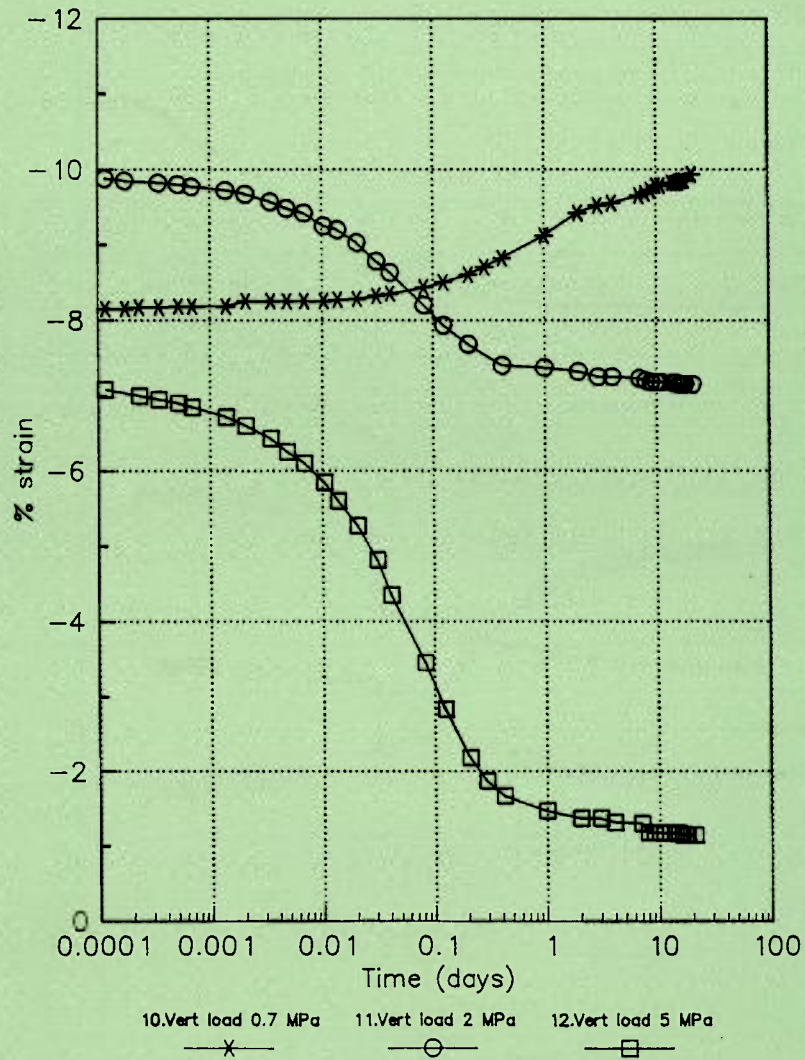
—○—

—×—

Different suction pressures
at constant vertical load 0.7 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN4_1

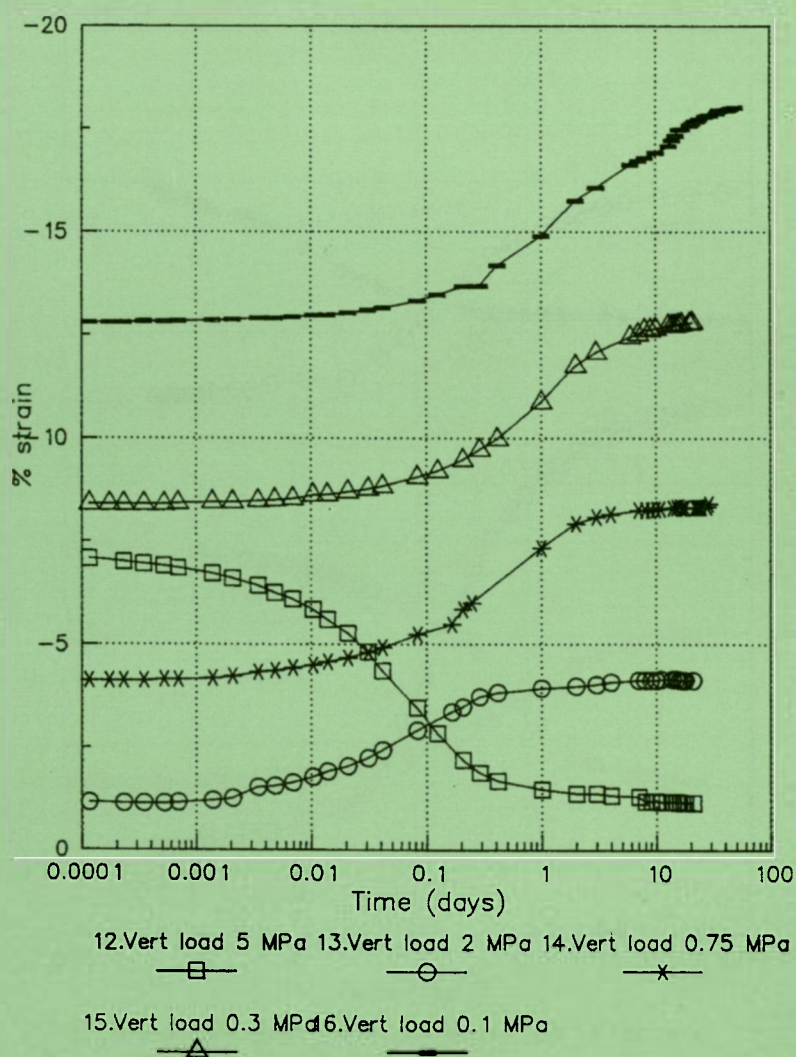
Initial dry density and w: 1.6 g/cm³, 12.2%



Loading at constant suction pressure 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN4_1

Initial dry density and w: 1.6 g/cm³, 12.2%



Unloading at constant suction pressure 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN5_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	17-12-92	End:	2-11-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

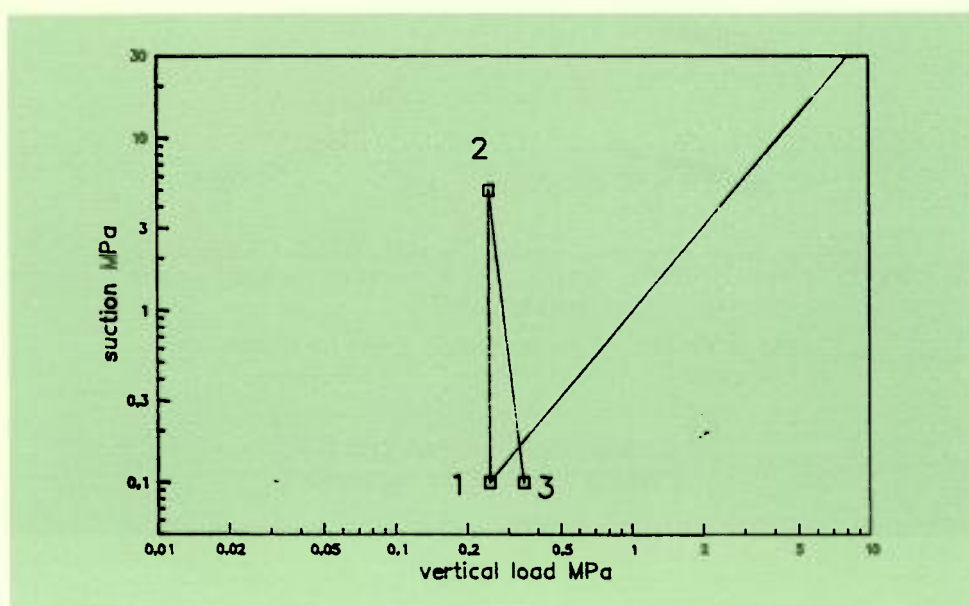
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.7 g	Assumed dry weight:	18.47 g
Water content:	12.1	Dry density:	1.60 g/cm ³

Final data

Weight:	25.21 g	Dry weight:	18.14 g
Water content:	37.4%	Initial dry density:	1.59 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.717 cm	Volume 1:	13.79 cm ³
		Dry dens. 1:	1.33 g/cm ³
Final h (deformation gauge:)	0.690 cm	Volume 2:	13.28 cm ³
		Dry dens. 2:	1.38 g/cm ³

Stress path:

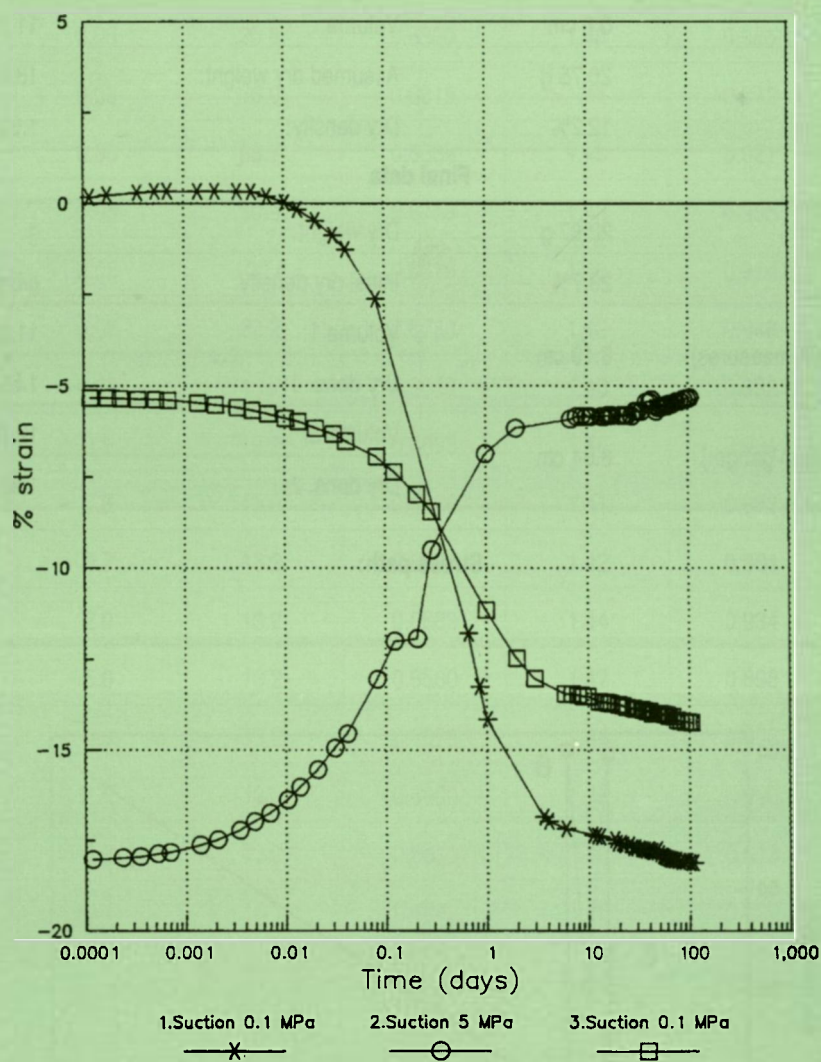


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN5_1

# Step	Vert. load MPa	Suction MPa	Final height h	Dry density	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.3	0.1	0.7087	1.35	1.053	51.3
2	0.3	5.0	0.6320	1.52	0.831	45.4
3	0.3	0.1	0.6855	1.40	0.986	49.6

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN5_1

Initial dry density 1.6 g/cm^3 , initial w 12.1%



Long duration experience.
Constant vertical load 0.3 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS1_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	12-6-92	End:	11-11-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

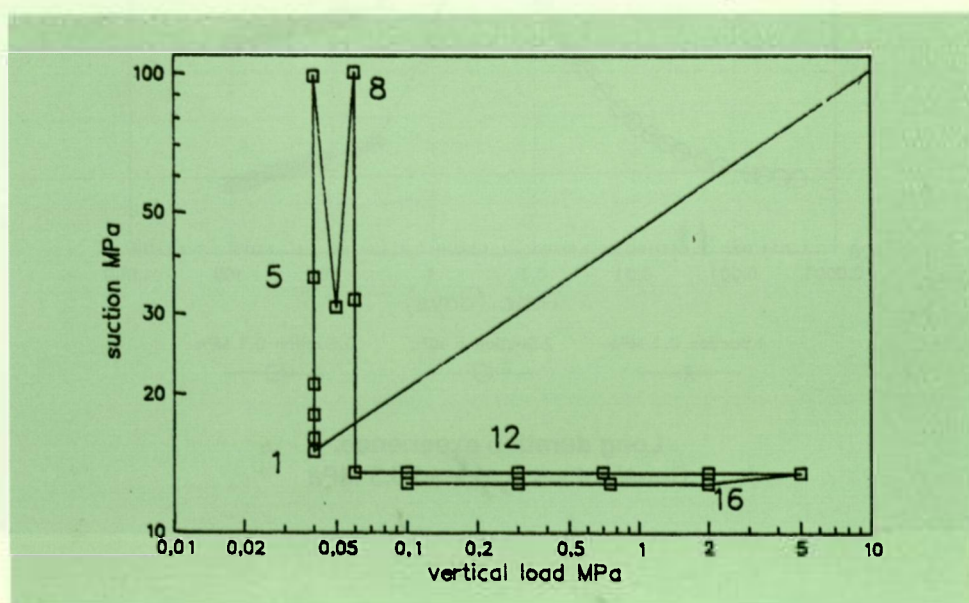
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.75 g	Assumed dry weight:	18.49 g
Water content:	12.2%	Dry density:	1.60 g/cm ³

Final data

Weight:	22.87 g	Dry weight:	g
Water content:	23.7%	Initial dry density:	g/cm ³
Final h (average 4 measures):	6.19 cm	Volume 1:	11.91 cm ³
		Dry dens. 1:	1.55 g/cm ³
Final h (deformation gauge:)	6.64 cm	Volume 2:	12.78 cm ³
		Dry dens. 2:	1.45 g/cm ³

Stress path:

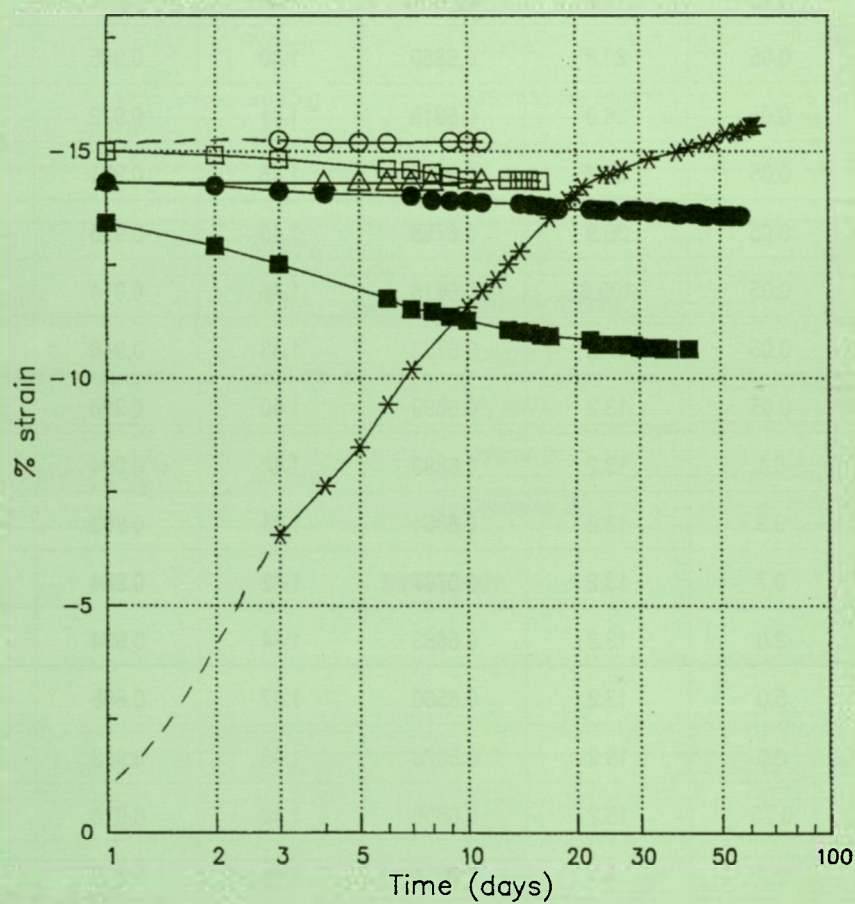


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS1_1

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.05	14.8	0.6934	1.39	1.006	50.0
2	0.05	15.8	0.6913	1.39	1.000	49.9
3	0.05	17.9	0.6861	1.40	0.985	49.5
4	0.05	20.8	0.6860	1.40	0.985	49.5
5	0.05	36.0	0.6815	1.41	0.972	49.1
6	0.05	98.7	0.6639	1.45	0.921	47.8
7	0.05	30.9	0.6758	1.43	0.955	48.7
8	0.05	100.6	0.6616	1.46	0.914	47.6
9	0.05	32.2	0.6733	1.43	0.948	48.5
10	0.05	13.2	0.6899	1.40	0.996	49.8
11	0.1	13.2	0.6893	1.40	0.994	49.7
12	0.3	13.2	0.6854	1.41	0.983	49.4
13	0.7	13.2	0.6787	1.42	0.964	48.9
14	2.0	13.2	0.6683	1.44	0.934	48.1
15	5.0	13.2	0.6560	1.47	0.898	47.2
16	2.0	13.2	0.6578	1.46	0.903	47.3
17	0.75	13.2	0.6600	1.46	0.910	47.5
18	0.3	13.2	0.6611	1.46	0.913	47.6
19	0.1	14.1	0.6642	1.45	0.922	47.8

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC **Consolidation curves. Montmorillonite EDS1_1**

Initial dry density 1.6 g/cm³, initial w 12.2%

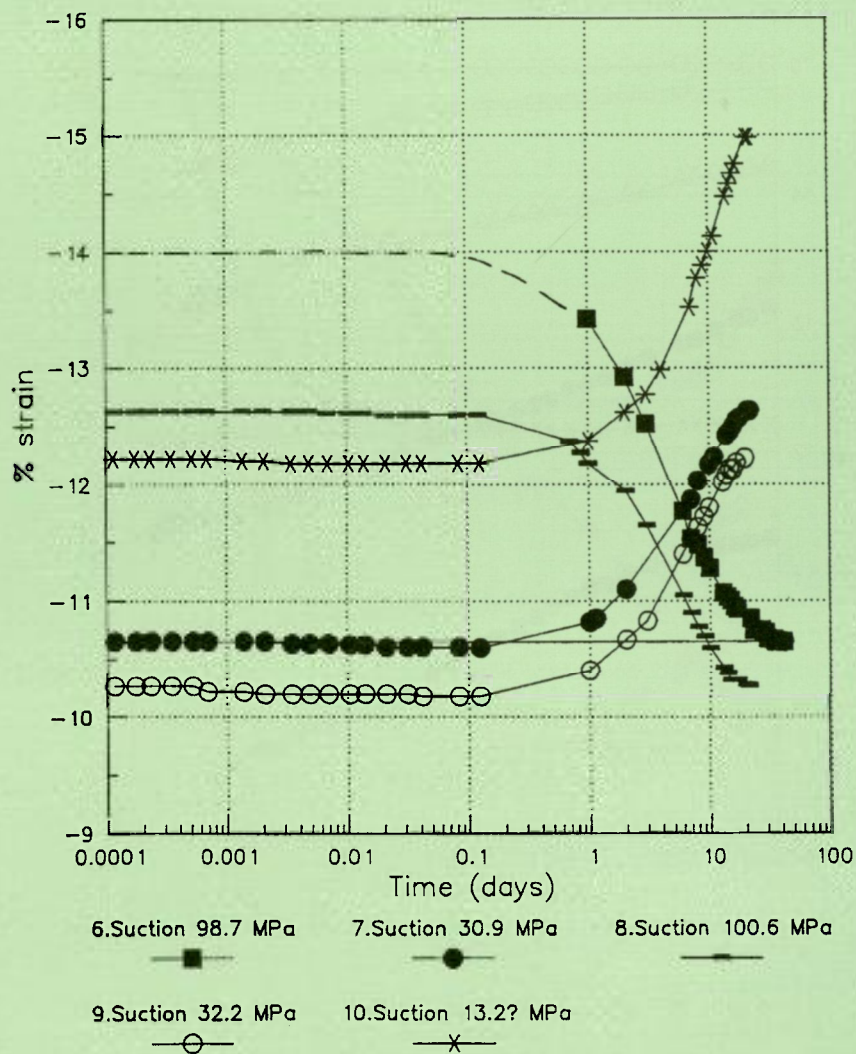


- | | | |
|--------------------|--------------------|--------------------|
| 1.Suction 14.8 MPa | 2.Suction 15.8 MPa | 3.Suction 17.9 MPa |
| — x — | — o — | — □ — |
| 4.Suction 20.8 MPa | 5.Suction 36.0 MPa | 6.Suction 98.7 MPa |
| — △ — | — ● — | — ■ — |

Increasing suction
at constant vertical load 0.05 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS1_1

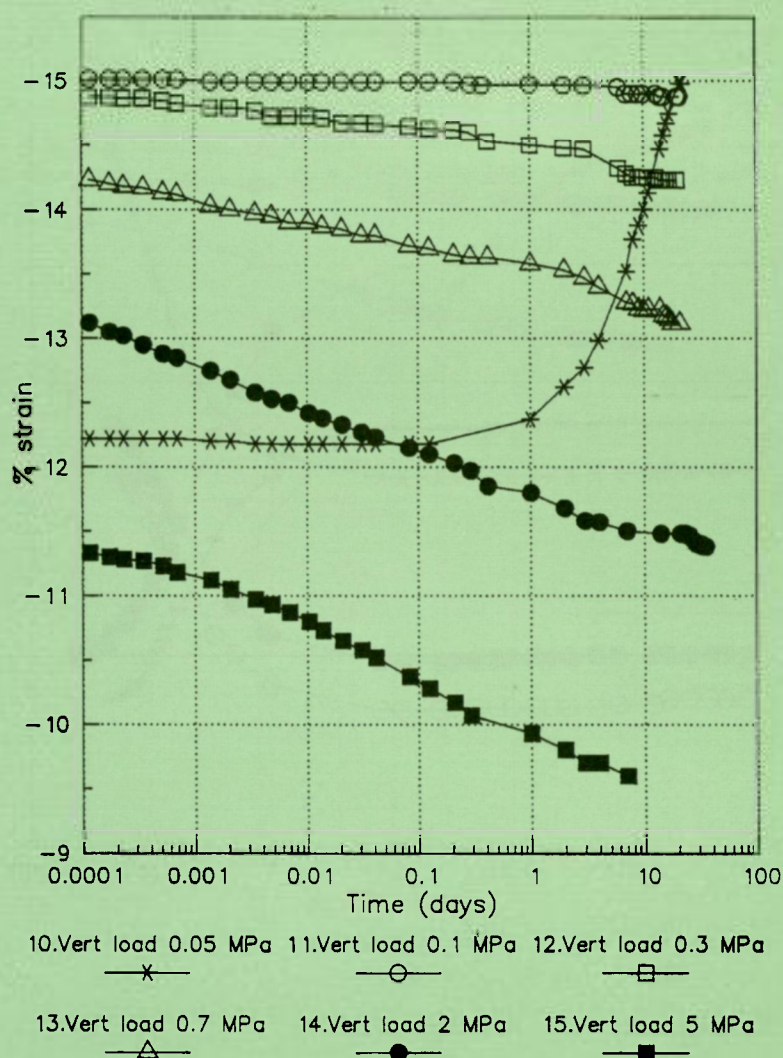
Initial dry density 1.6 g/cm^3 , initial w 12.2%



**Decreasing suction pressure
 at constant vertical load 0.05 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC **Consolidation curves. Montmorillonite EDS1_1**

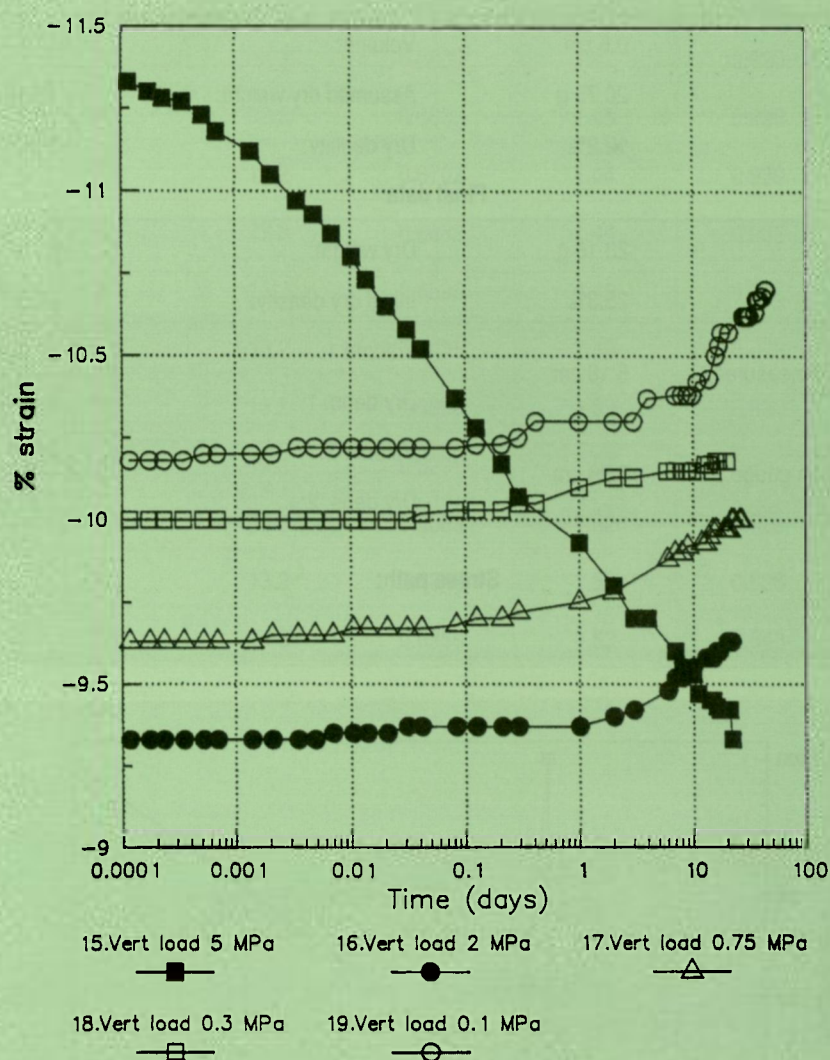
Initial dry density 1.6 g/cm³, initial w 12.2%



Loading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS1_1

Initial dry density and w: 1.6 g/cm³, 12.2%



Unloading at constant suction pressure 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS2_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	12-6-92	End:	11-11-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

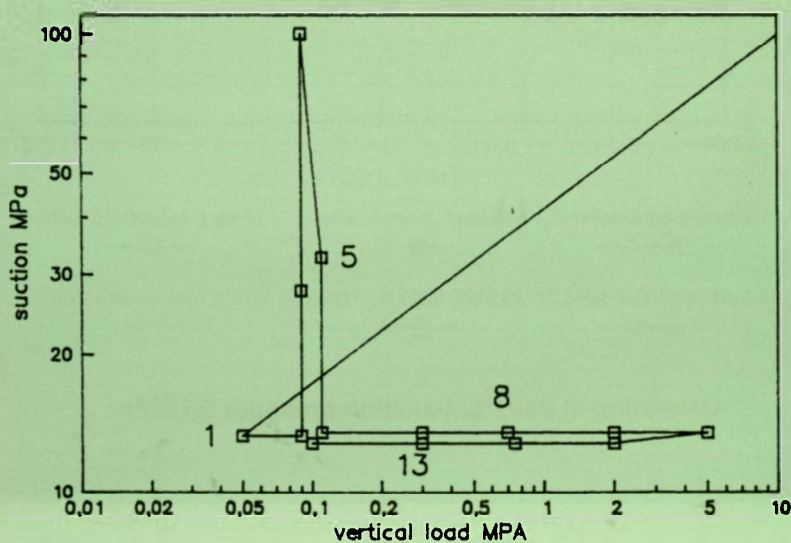
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.75 g	Assumed dry weight:	18.49 g
Water content:	12.2%	Dry density:	1.60 g/cm ³

Final data

Weight:	23.16 g	Dry weight:	g
Water content:	25.3%	Initial dry density:	g/cm ³
Final h (average 4 measures):	6.18 cm	Volume 1:	11.90 cm ³
		Dry dens. 1:	1.55 g/cm ³
Final h (deformation gauge:)	6.36 cm	Volume 2:	12.23 cm ³
		Dry dens. 2:	1.51 g/cm ³

Stress path:

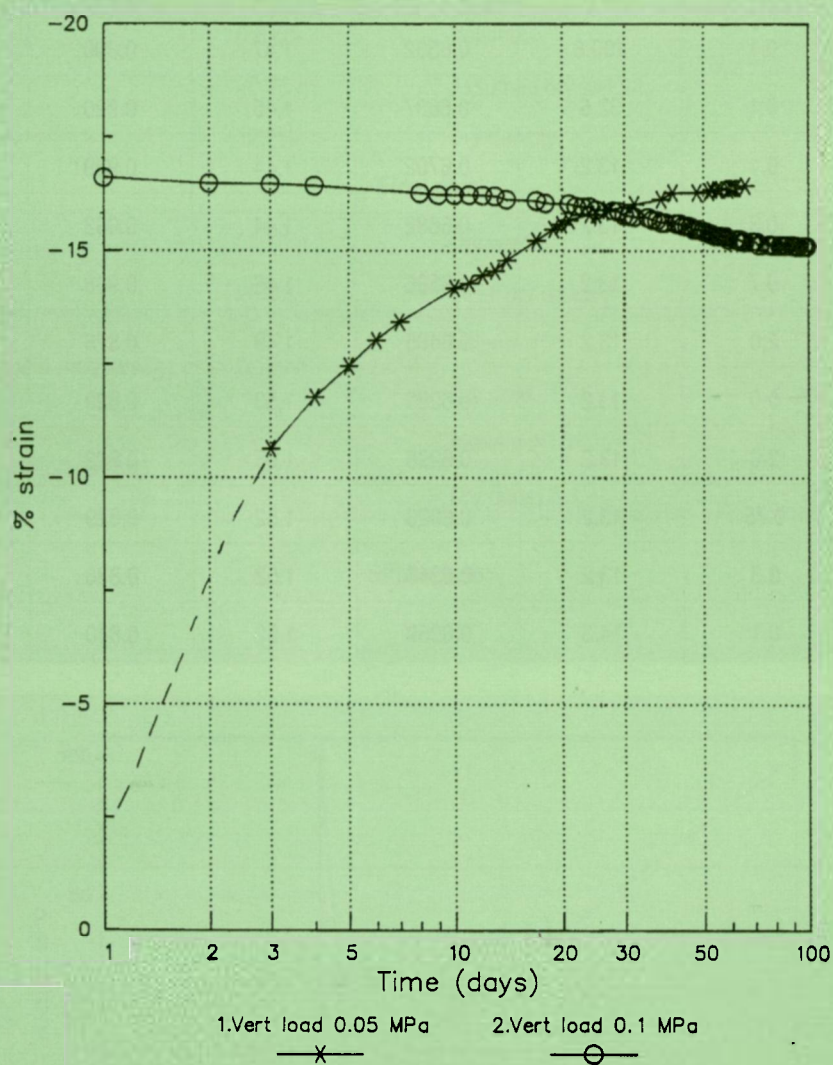


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS2_1

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.05	13.6	0.6986	1.38	1.021	50.4
2	0.1	13.9	0.6906	1.40	0.998	49.8
3	0.1	27.6	0.6791	1.42	0.965	49.0
4	0.1	100.6	0.6532	1.47	0.890	46.9
5	0.1	32.6	0.6637	1.45	0.920	47.8
6	0.1	13.2	0.6702	1.44	0.939	48.3
7	0.3	13.2	0.6682	1.44	0.933	48.1
8	0.7	13.2	0.6596	1.46	0.908	47.5
9	2.0	13.2	0.6485	1.49	0.876	46.6
10	5.0	13.2	0.6292	1.53	0.820	44.9
11	2.0	13.2	0.6296	1.53	0.822	45.0
12	0.75	13.2	0.6323	1.52	0.829	45.2
13	0.3	13.2	0.6346	1.52	0.836	45.4
14	0.1	14.3	0.6359	1.52	0.840	45.5

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS2_1

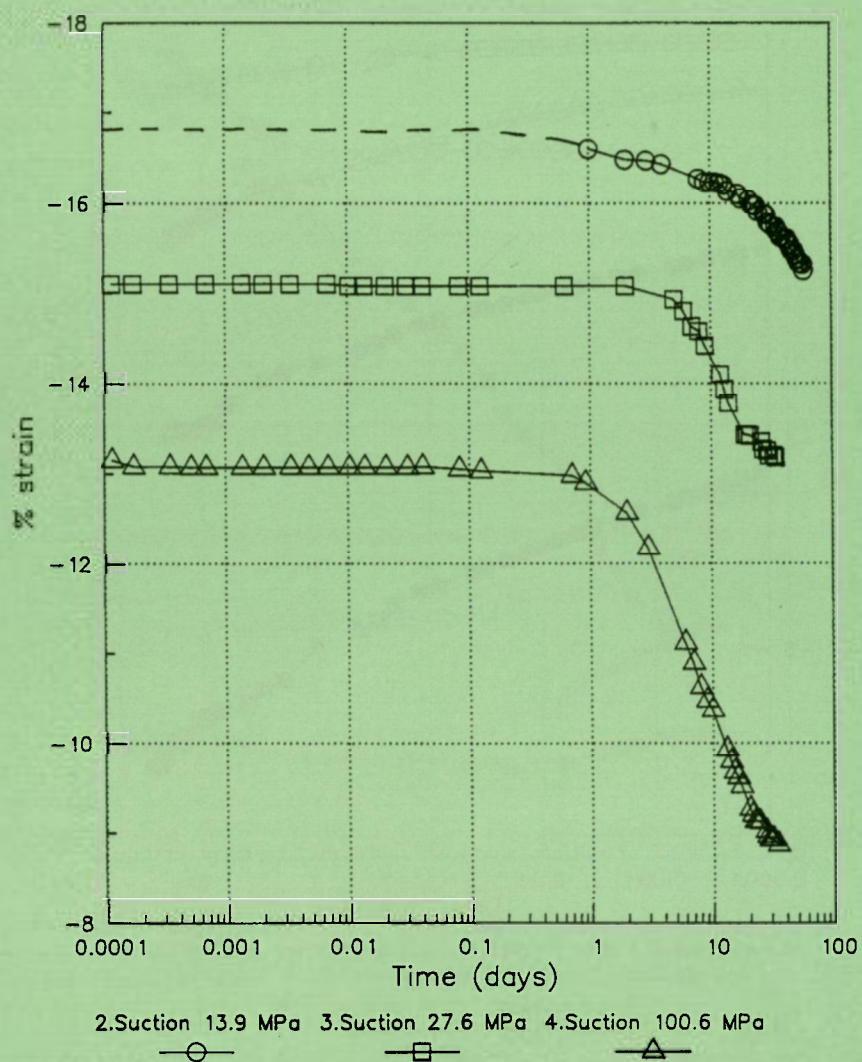
Initial dry density 1.6 g/cm³, initial w 12.2%



Loading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS2_1

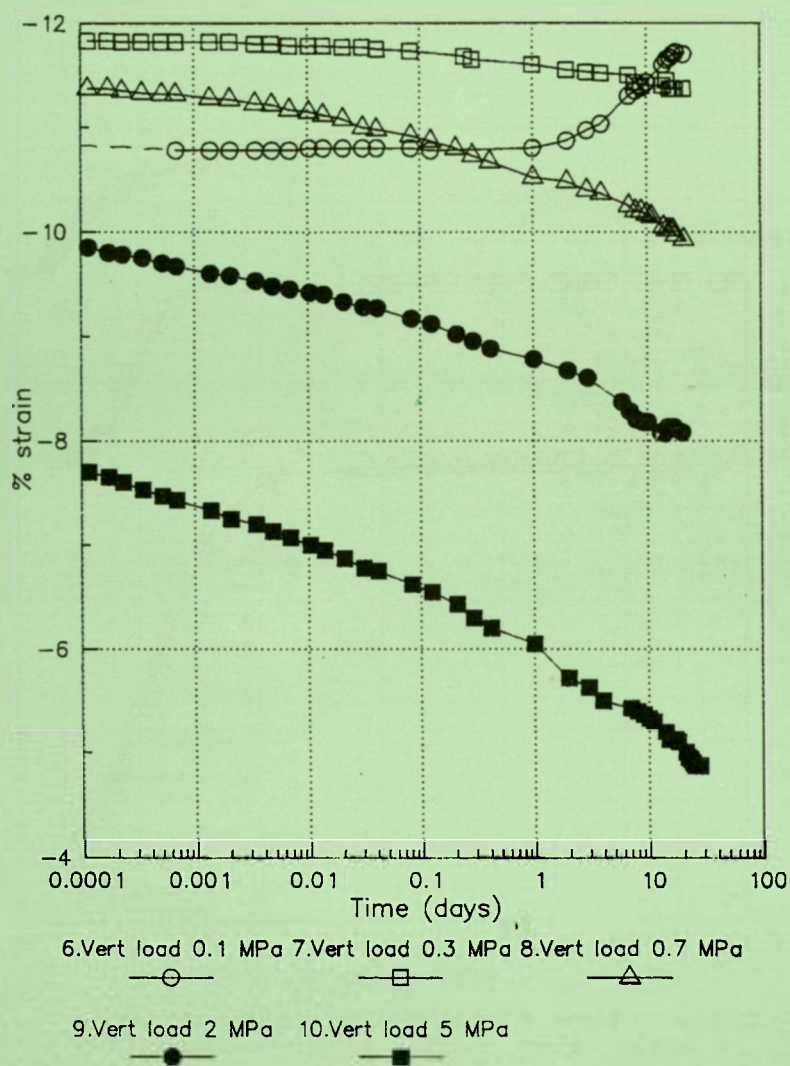
Initial dry density 1.6 g/cm^3 , initial w 12.2%



Increasing suction
at constant vertical load 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS2_1

Initial dry density 1.6 g/cm³, initial w 12.2%

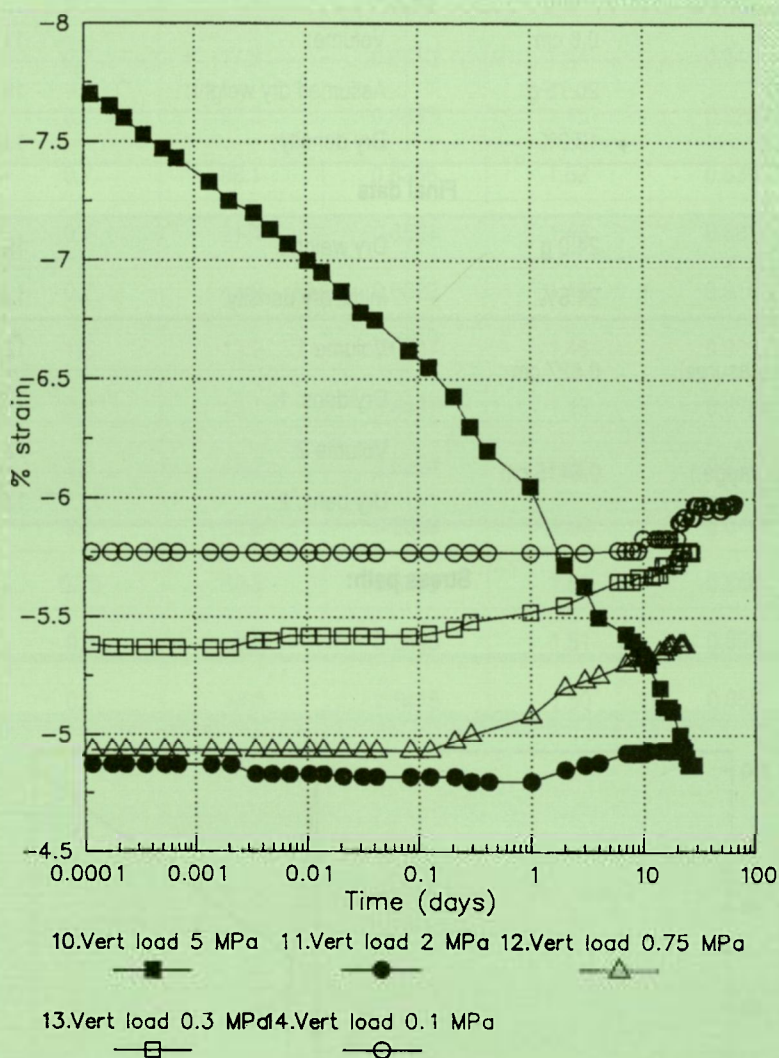


Loading at constant suction pressure 13.2 MPa



SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS2_1

Initial dry density 1.6 g/cm³, initial w 12.2%



Unloading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS4_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	12-6-92	End:	27-9-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

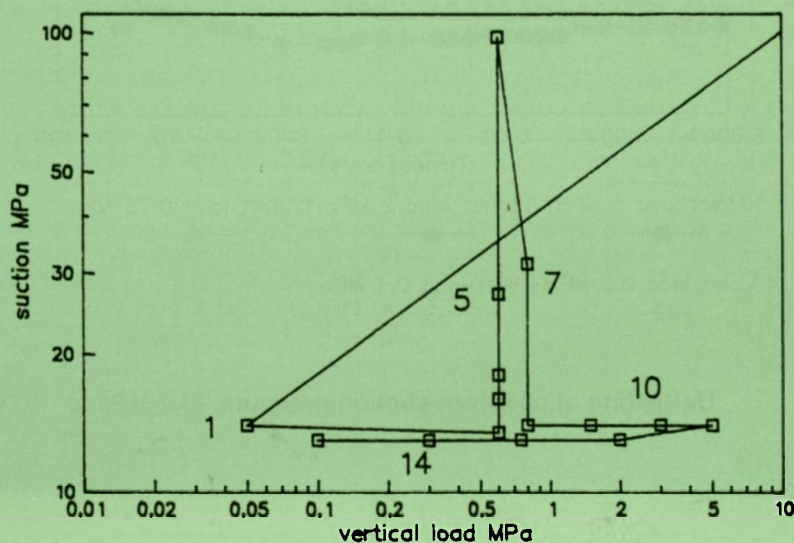
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.75 g	Assumed dry weight:	18.49 g
Water content:	12.2%	Dry density:	1.60 g/cm ³

Final data

Weight:	24.0 g	Dry weight:	19.28 g
Water content:	24.5%	Initial dry density:	1.67 g/cm ³
Final h (average 4 measures):	0.627 cm	Volume 1:	12.06 cm ³
		Dry dens. 1:	1.60 g/cm ³
Final h (deformation gauge:)	0.6415 cm	Volume 2:	12.34 cm ³
		Dry dens. 2:	1.56 g/cm ³

Stress path:

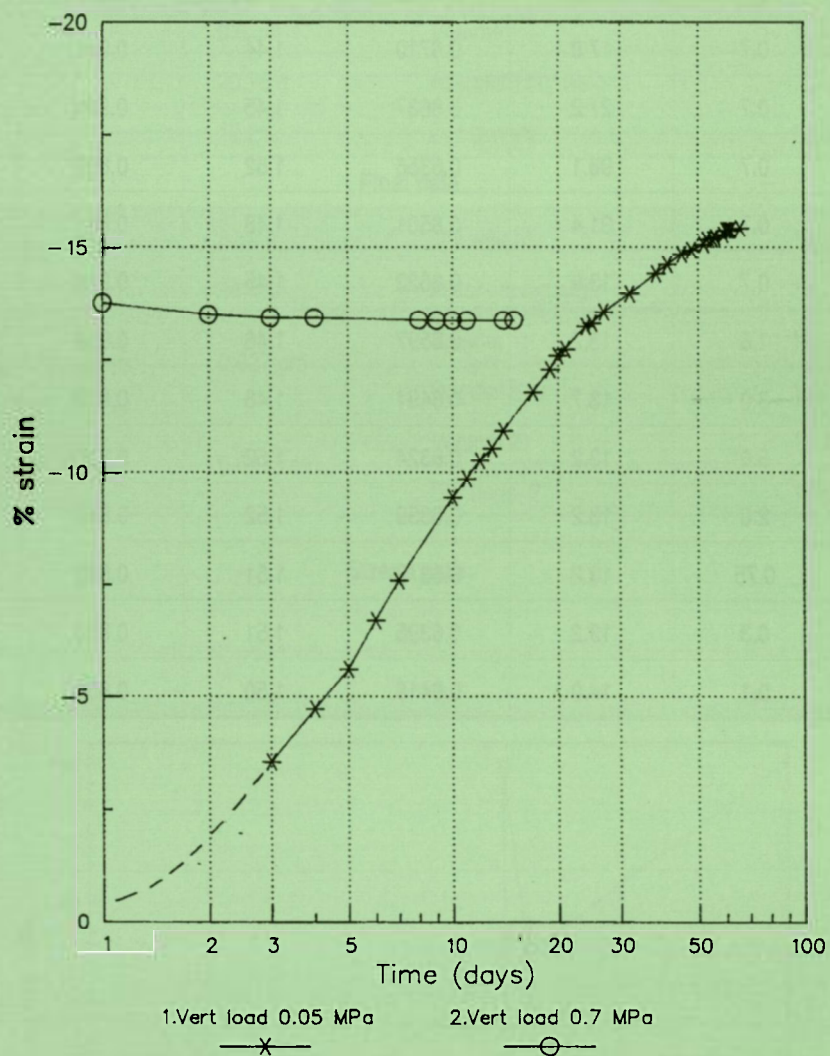


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS4_1

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.05	13.9	0.6926	1.39	1.004	50.0
2	0.7	13.2	0.6802	1.42	0.968	49.1
3	0.7	15.8	0.6762	1.42	0.956	48.8
4	0.7	17.8	0.6710	1.44	0.941	48.4
5	0.7	27.2	0.6637	1.45	0.920	47.8
6	0.7	98.1	0.6356	1.52	0.839	45.5
7	0.7	31.4	0.6501	1.48	0.881	46.7
8	0.7	13.9	0.6622	1.45	0.916	47.7
9	1.5	13.2	0.6597	1.46	0.909	47.5
10	3.0	13.7	0.6491	1.48	0.878	46.6
11	5.0	13.2	0.6324	1.52	0.830	45.2
12	2.0	13.2	0.6359	1.52	0.840	45.5
13	0.75	13.2	0.6379	1.51	0.846	45.7
14	0.3	13.2	0.6395	1.51	0.850	45.8
15	0.1	14.0	0.6415	1.50	0.856	46.0

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_1

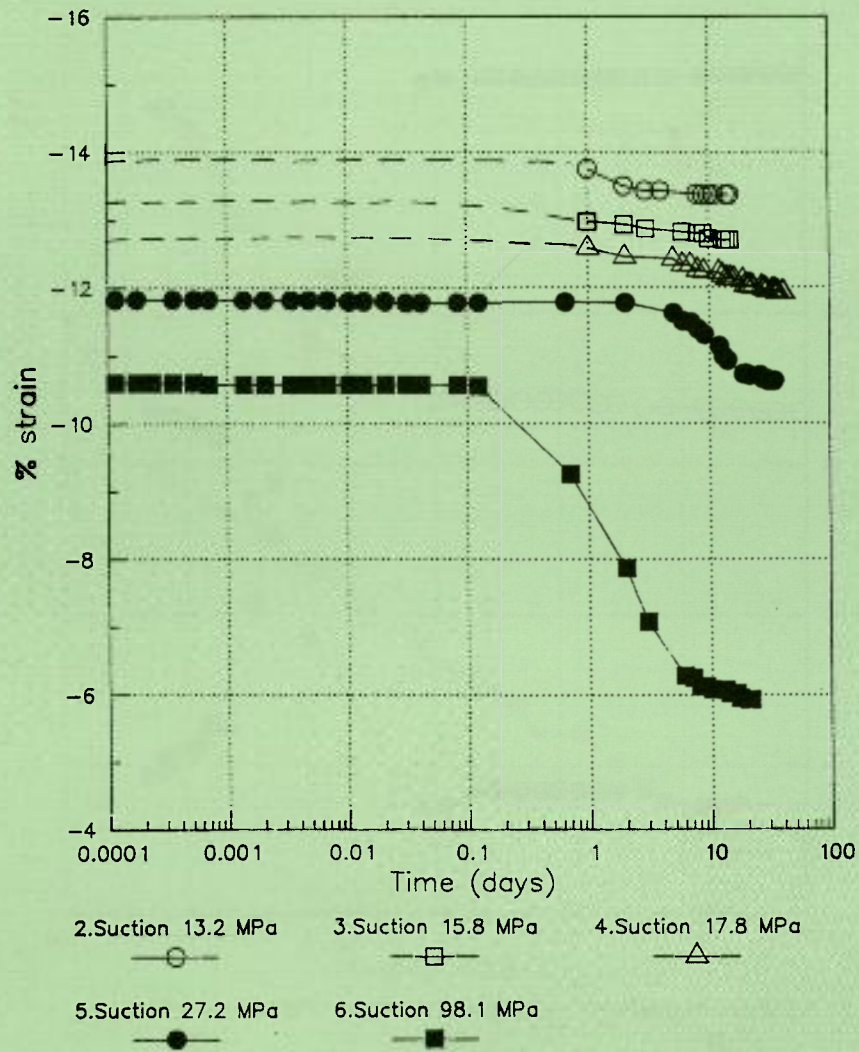
Initial dry density 1.6 g/cm³, initial w 12.2%



Loading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_1

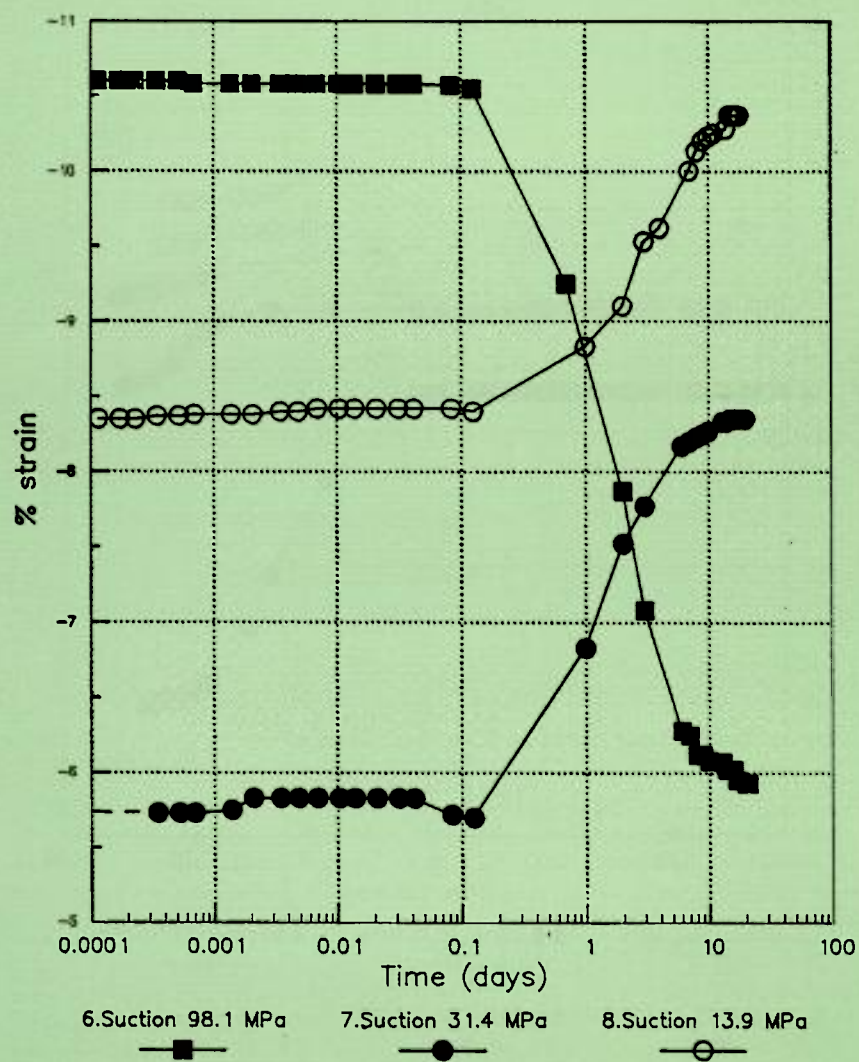
Initial dry density 1.6 g/cm^3 , initial w 12.2%



Increasing suction-
at constant vertical load 0.7 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_1

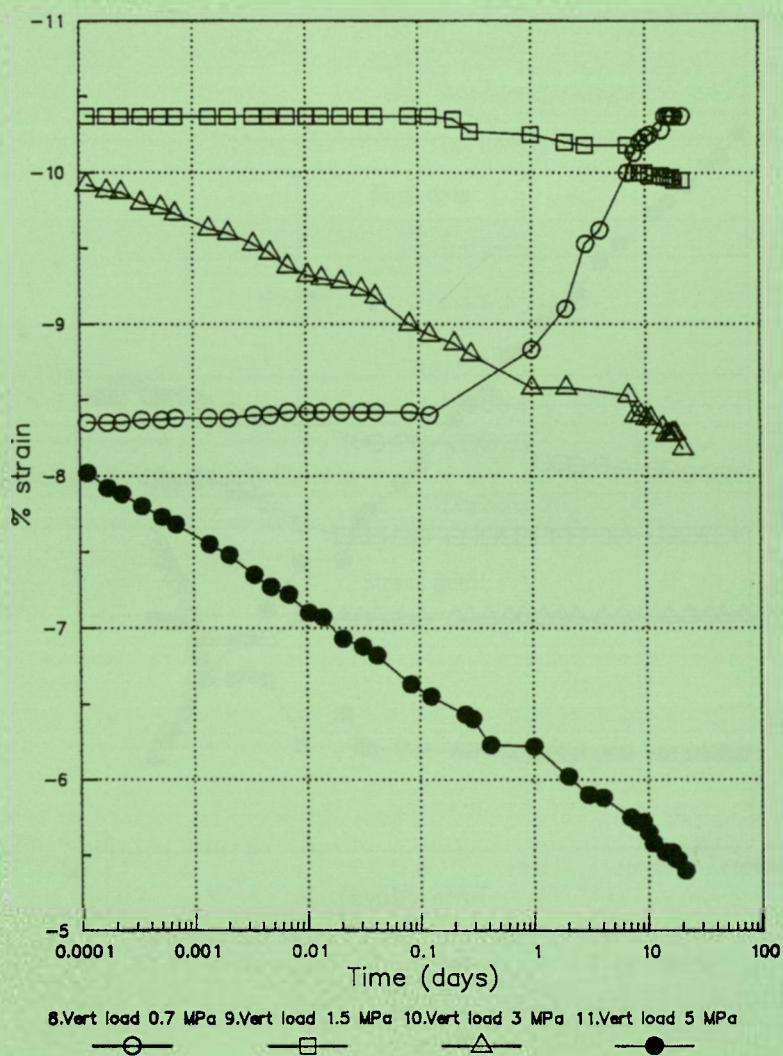
Initial dry density 1.6 g/cm³, initial w 12.2%



Decreasing suction
at constant vertical load 0.7 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_1

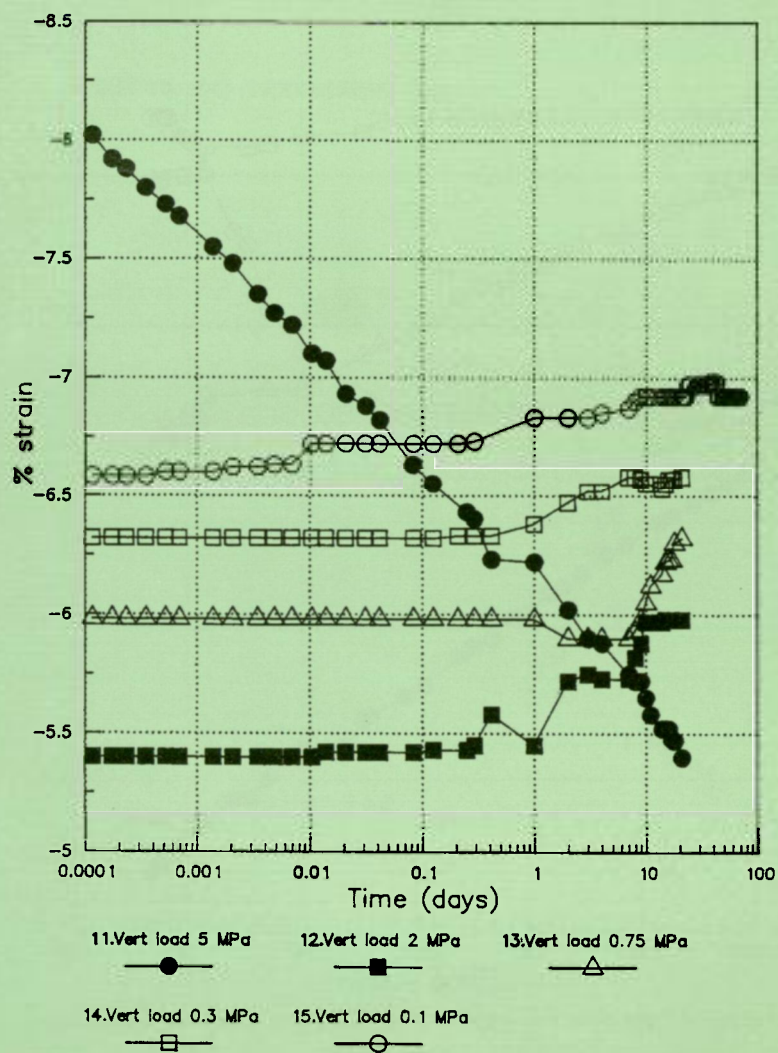
Initial dry density 1.6 g/cm^3 , initial w 12.2%



Loading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_1

Initial dry density 1.6 g/cm³, initial w 12.2%



Unloading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS5_1		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	12-6-92	End:	27-9-93

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

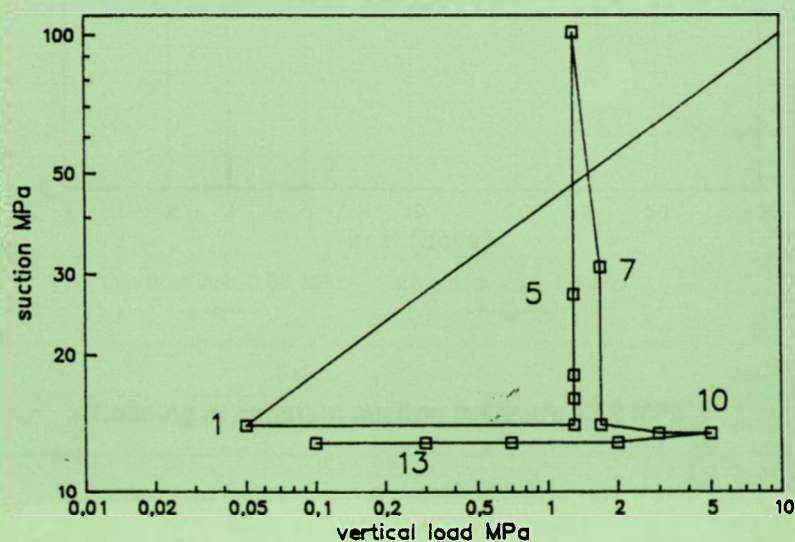
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.8 g	Assumed dry weight:	18.54 g
Water content:	12.2%	Dry density:	1.60 g/cm ³

Final data

Weight:	23.2 g	Dry weight:	18.66 g
Water content:	24.5%	Initial dry density:	1.62 g/cm ³
Final h (average 4 measures):	0.616 cm	Volume 1:	11.85 cm ³
		Dry dens. 1:	1.57 g/cm ³
Final h (deformation gauge:)	0.6308 cm	Volume 2:	12.14 cm ³
		Dry dens. 2:	1.54 g/cm ³

Stress path:

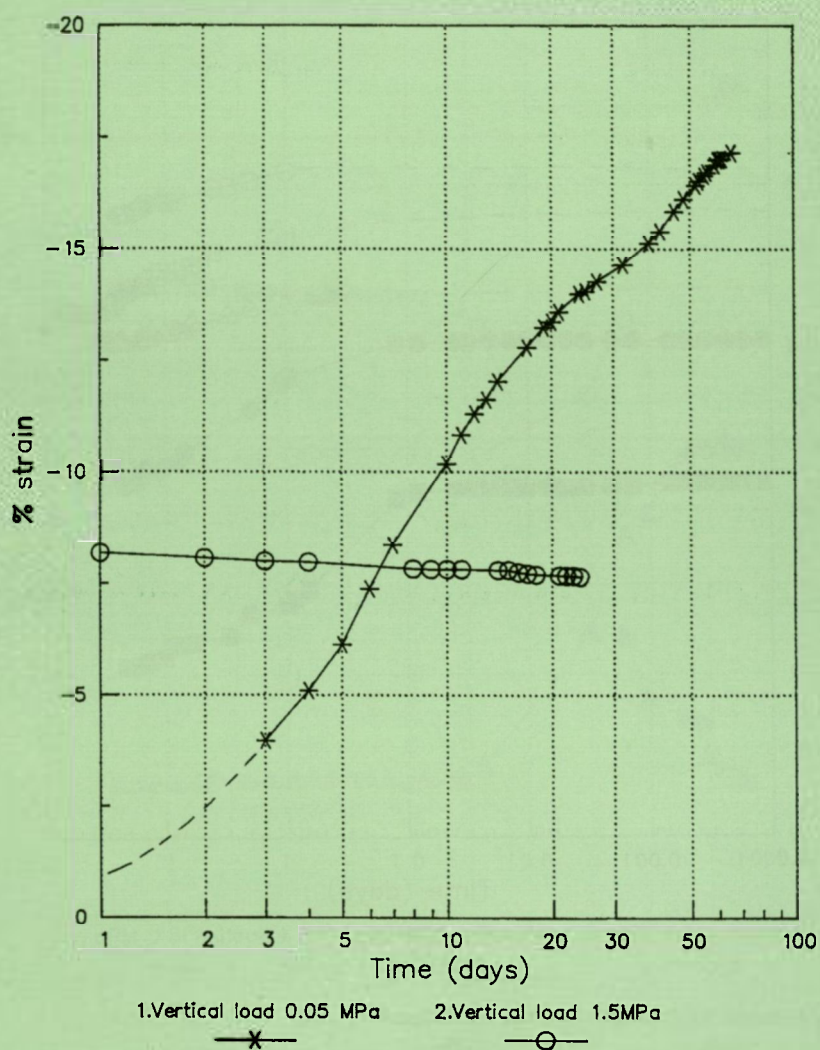


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS5_1

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.05	13.9	0.7029	1.37	1.028	50.7
2	1.5	13.9	0.6459	1.49	0.864	46.3
3	1.5	15.9	0.6388	1.51	0.843	45.7
4	1.5	18.0	0.6364	1.51	0.836	45.5
5	1.5	27.2	0.6260	1.54	0.806	44.6
6	1.5	100.6	0.6126	1.57	0.768	43.4
7	1.5	31.4	0.6214	1.55	0.793	44.2
8	1.5	14.1	0.6314	1.53	0.822	45.1
9	3.0	13.2	0.6273	1.54	0.810	44.8
10	5.0	13.2	0.6158	1.56	0.777	43.7
11	2.0	13.2	0.6197	1.55	0.788	44.1
12	7.5	13.2	0.6267	1.54	0.808	44.7
13	0.3	13.2	0.6295	1.53	0.816	44.9
14	0.1	13.9	0.6308	1.53	0.820	45.1

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_1

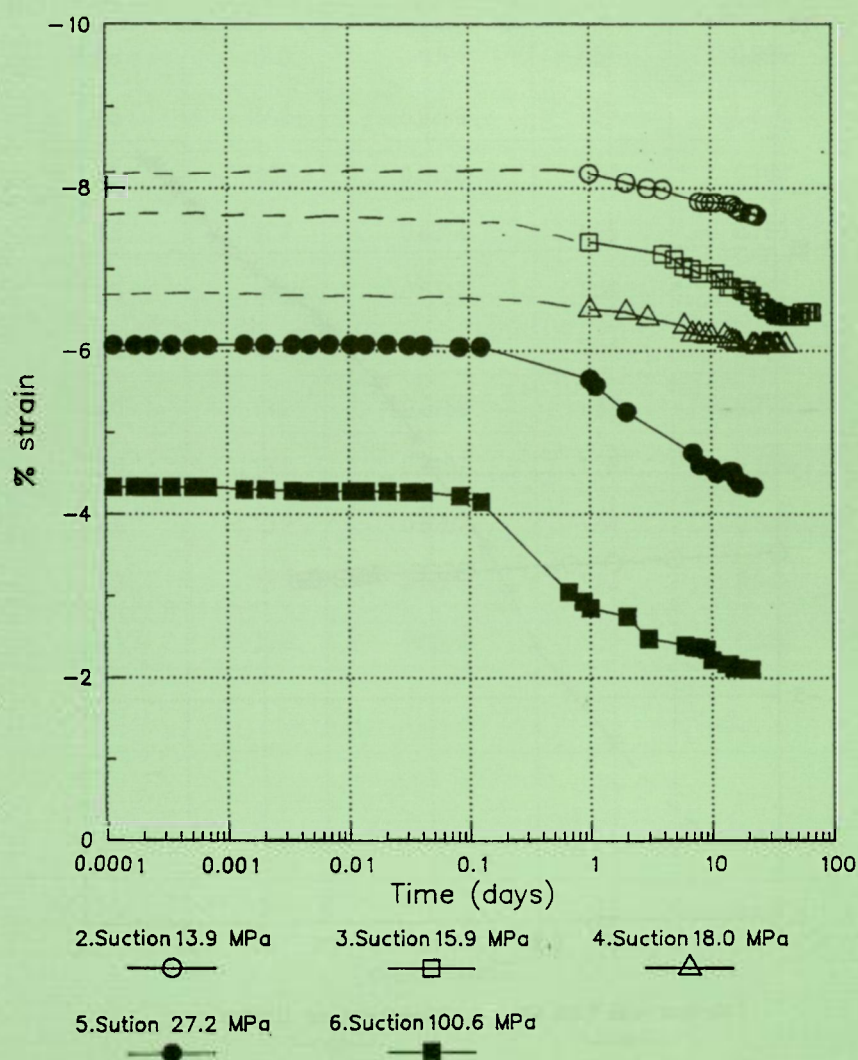
Initial dry density 1.6 g/cm^3 , initial w 12.2%



Loading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_1

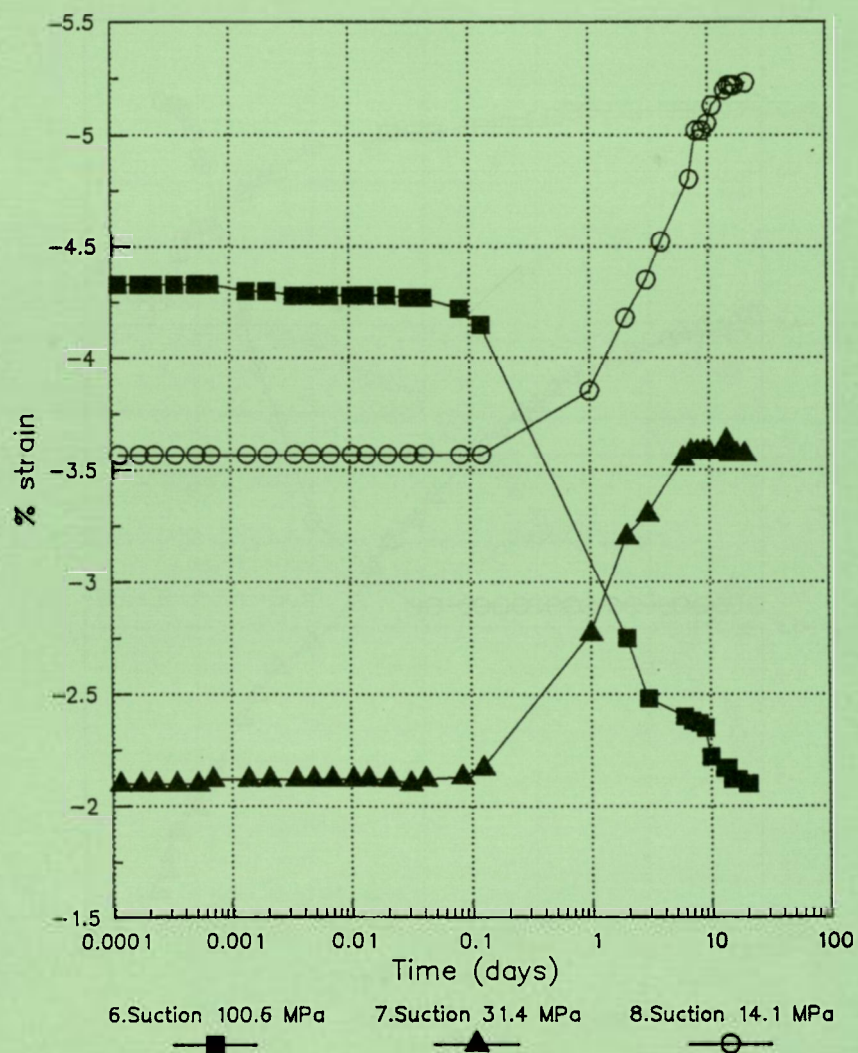
Initial dry density 1.6 g/cm³, initial w 12.2%



Increasing suction pressure
at constant vertical load 1.5 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_1

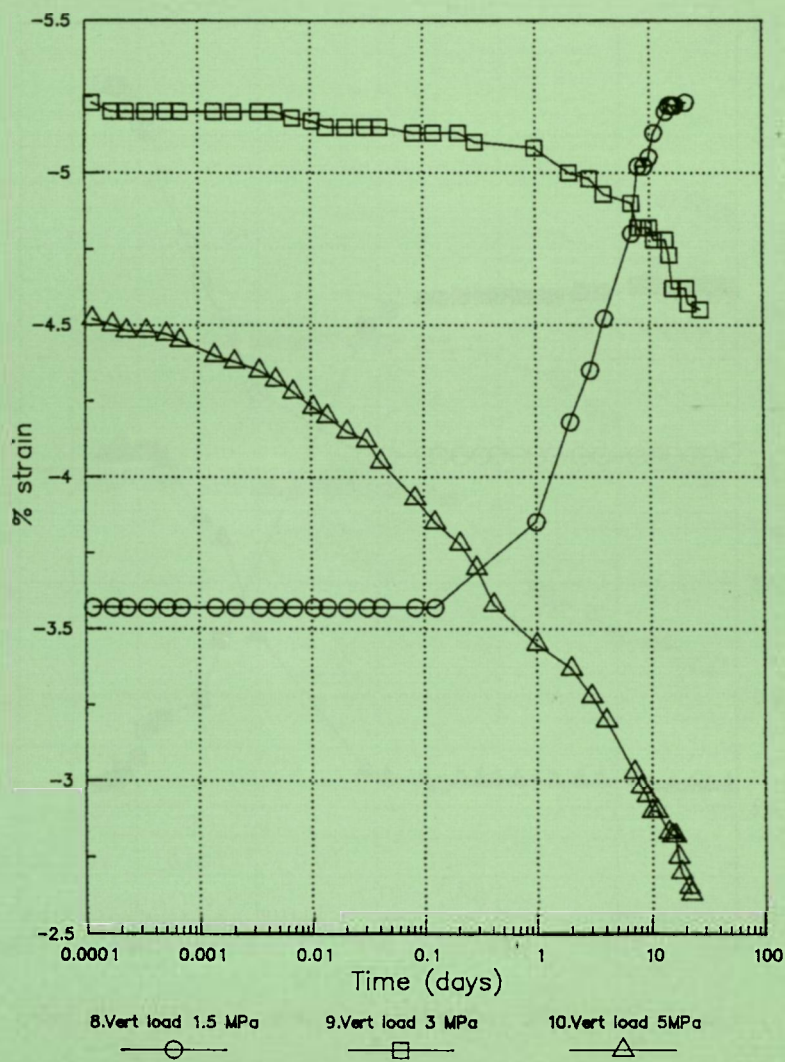
Initial dry density 1.6 g/cm³, initial w 12.2%



Decreasing suction pressure
 at constant vertical load 1.5 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_1

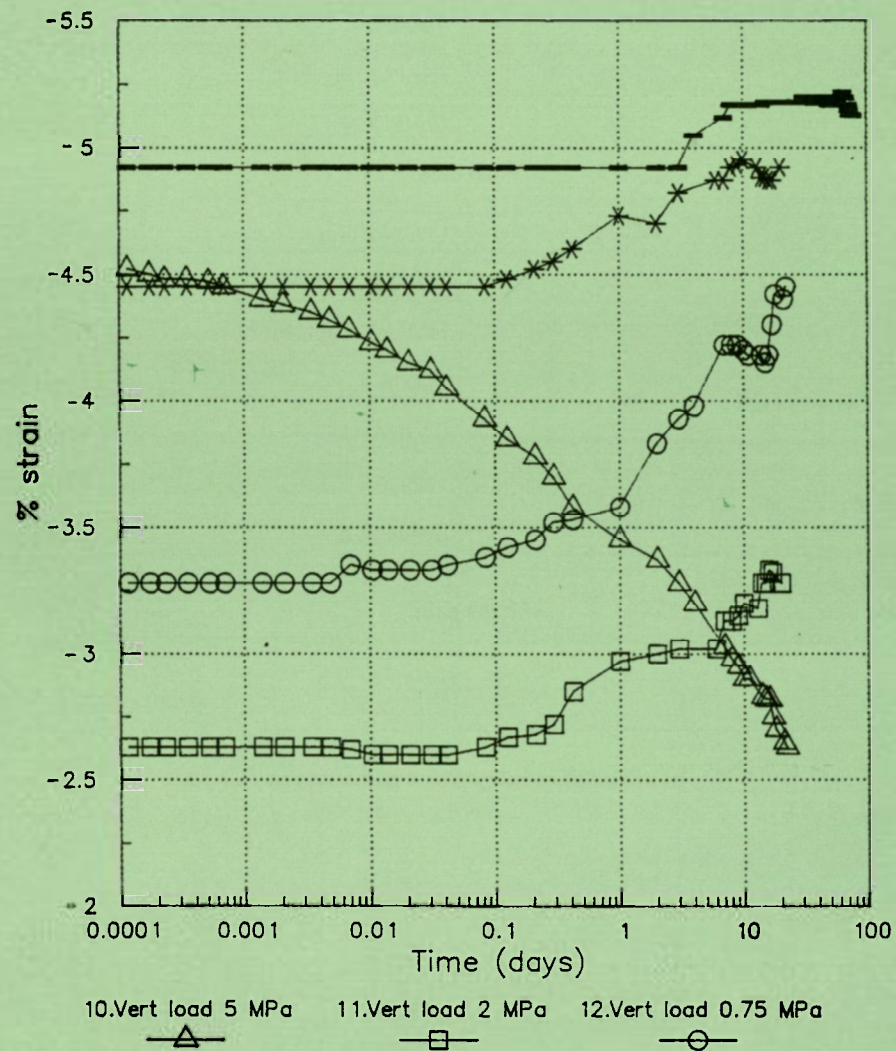
Initial dry density 1.6 g/cm³, initial w 12.2%



Loading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_1

Initial dry density 1.6 g/cm³, initial w 12.2%



Unloading at constant suction pressure 13.2 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN1_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	18-1-94	End:	15-11-94

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

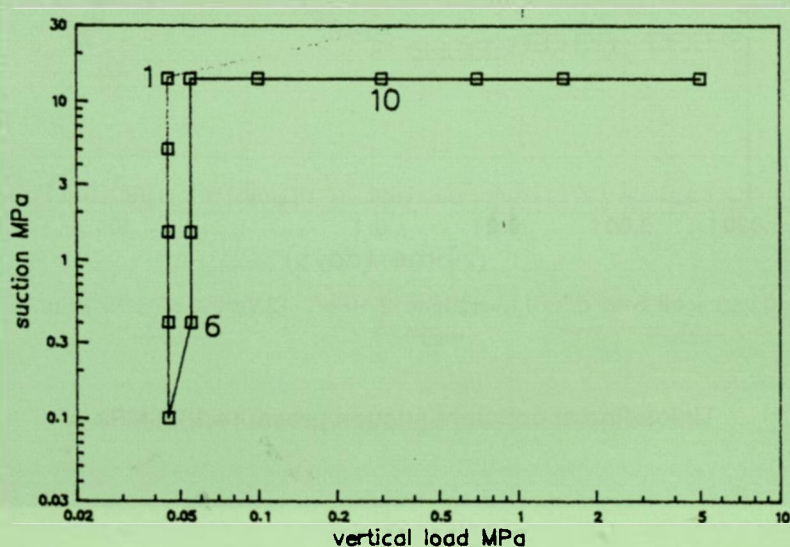
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.6 g	Assumed dry weight:	18.51 g
Water content:	11.3%	Dry density:	1.60 g/cm ³

Final data

Weight:	22.54 g	Dry weight:	18.51 g
Water content:	21.8%	Initial dry density:	1.60 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.597 cm	Volume 1:	11.49 cm ³
		Dry dens. 1:	1.61 g/cm ³
Final h (deformation gauge:)	0.6991 cm	Volume 2:	13.45 cm ³
		Dry dens. 2:	1.38 g/cm ³

Stress path:

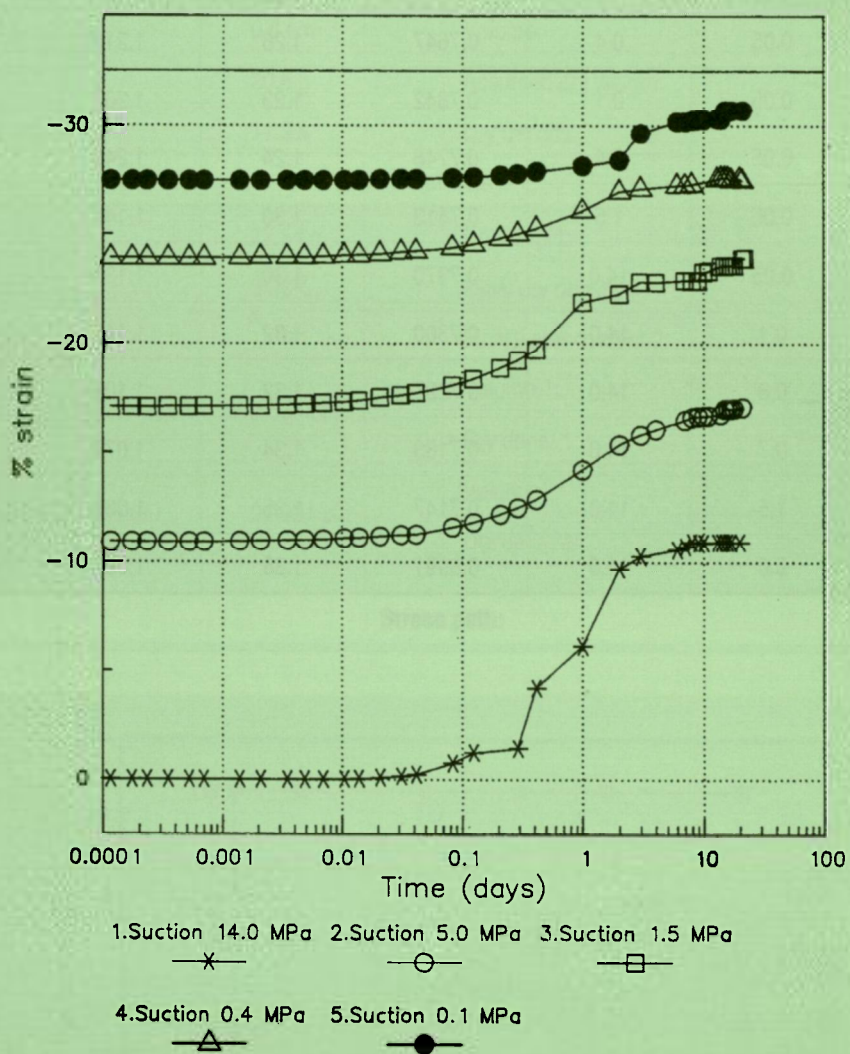


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN1_2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.0
1	0.05	14.0	0.6655	1.45	0.924	48.0
2	0.05	5.0	0.7025	1.37	1.031	50.8
3	0.05	1.5	0.7435	1.29	1.149	53.5
4	0.05	0.4	0.7647	1.26	1.210	54.8
5	0.05	0.1	0.7842	1.23	1.267	55.9
6	0.05	0.4	0.7748	1.24	1.240	55.3
7	0.05	1.5	0.7413	1.30	1.143	55.3
8	0.05	14.0	0.7370	1.30	1.130	55.1
9	0.1	14.0	0.7300	1.32	1.110	52.6
10	0.3	14.0	0.7297	1.32	1.109	52.6
11	0.7	14.0	0.7183	1.34	1.076	51.8
12	1.5	14.0	0.7147	1.35	1.066	51.6
13	5.0	14.0	0.6991	1.38	1.021	50.5

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN **Consolidation curves. Montmorillonite EDN1_2**

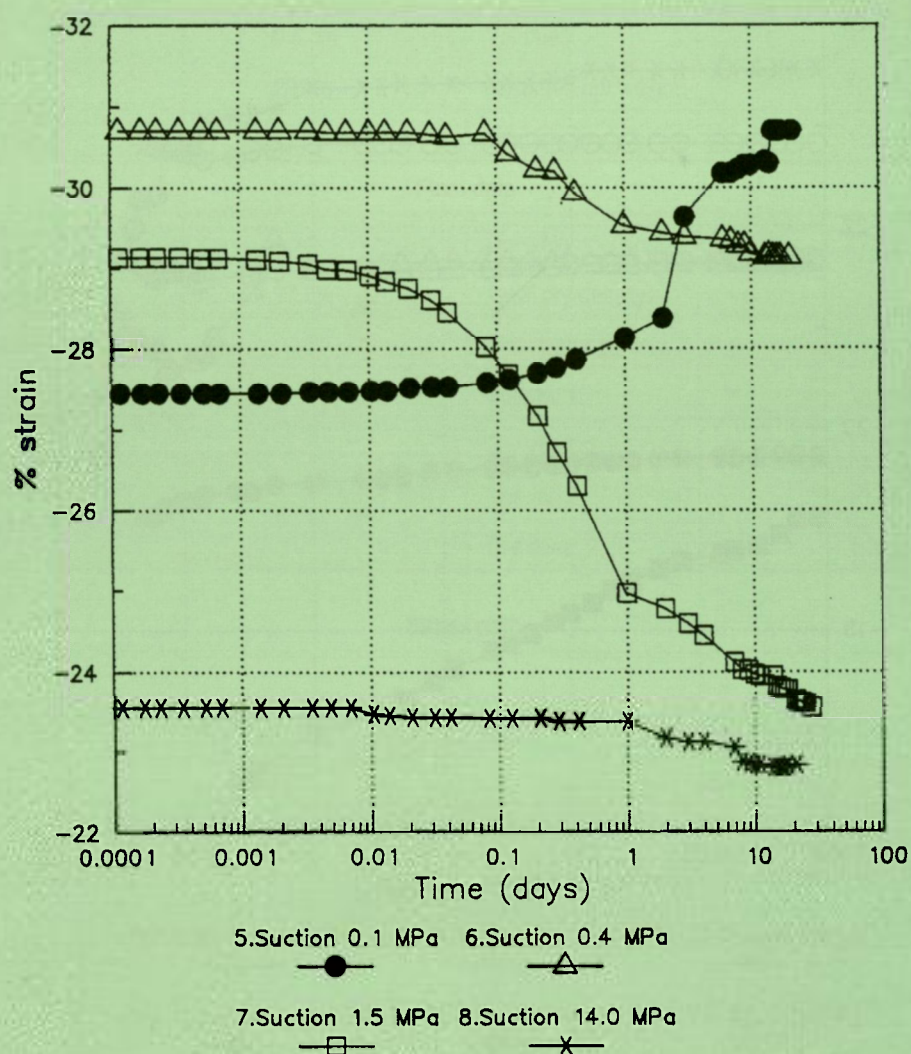
Initial dry density and w: 1.6 g/cm³, 11.3%



**Decreasing suction pressure
at constant vertical load 0.05 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN1_2

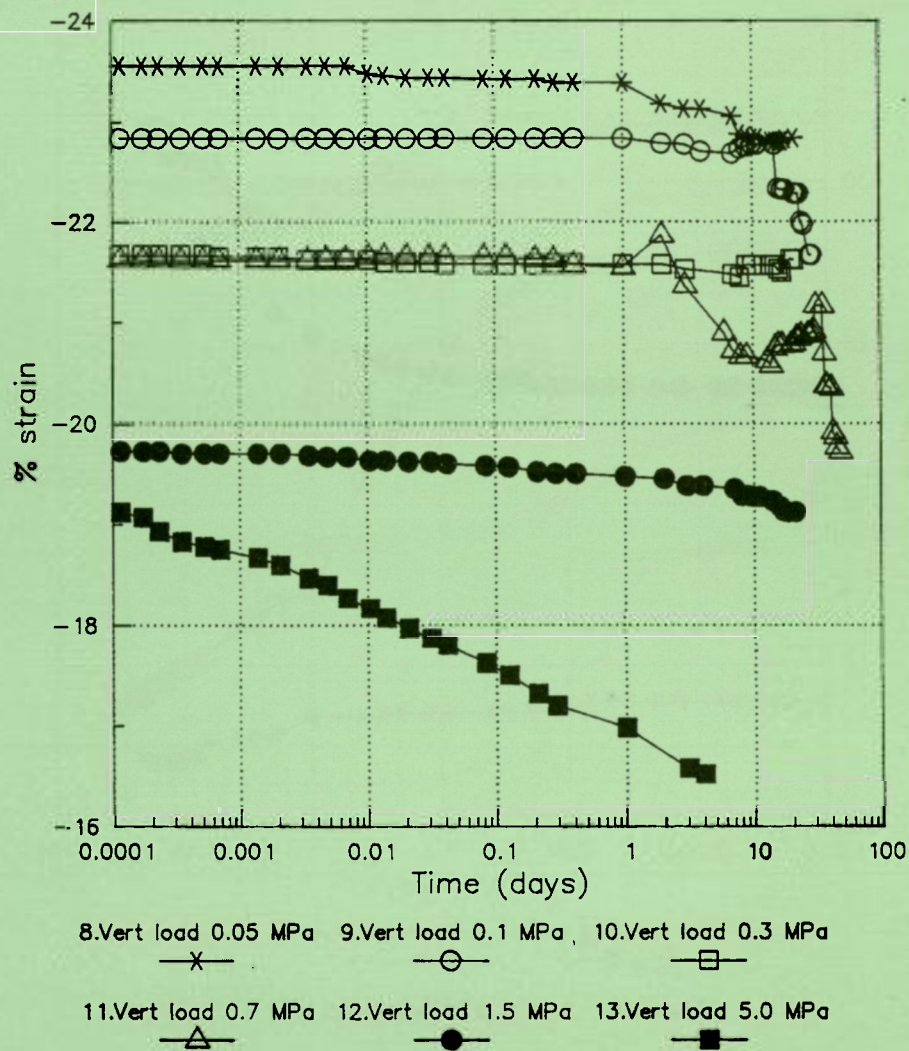
Initial dry density and w: 1.6 g/cm³, 11.3%



**Increasing suction pressure
 at constant vertical load 0.05 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN1_2

Initial dry density and w: 1.6 g/cm³, 11.3%



Increasing vertical load
at constant suction pressure 14.0 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN2_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	16-2-94	End:	30-6-94

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

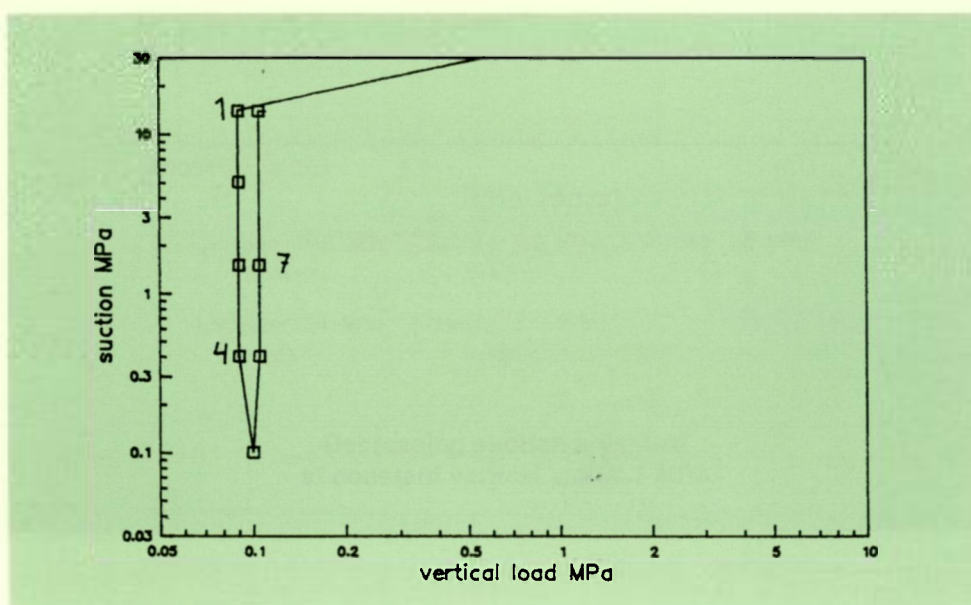
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.5 g	Assumed dry weight:	18.47 g
Water content:	11.0%	Dry density:	1.60 g/cm ³

Final data

Weight:		Dry weight:	
Water content:	27.6%	Initial dry density:	
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.697 cm	Volume 1:	13.41 cm ³
		Dry dens. 1:	1.38 g/cm ³
Final h (deformation gauge:)	0.7111 cm	Volume 2:	13.68 cm ³
		Dry dens. 2:	1.35 g/cm ³

Stress path:

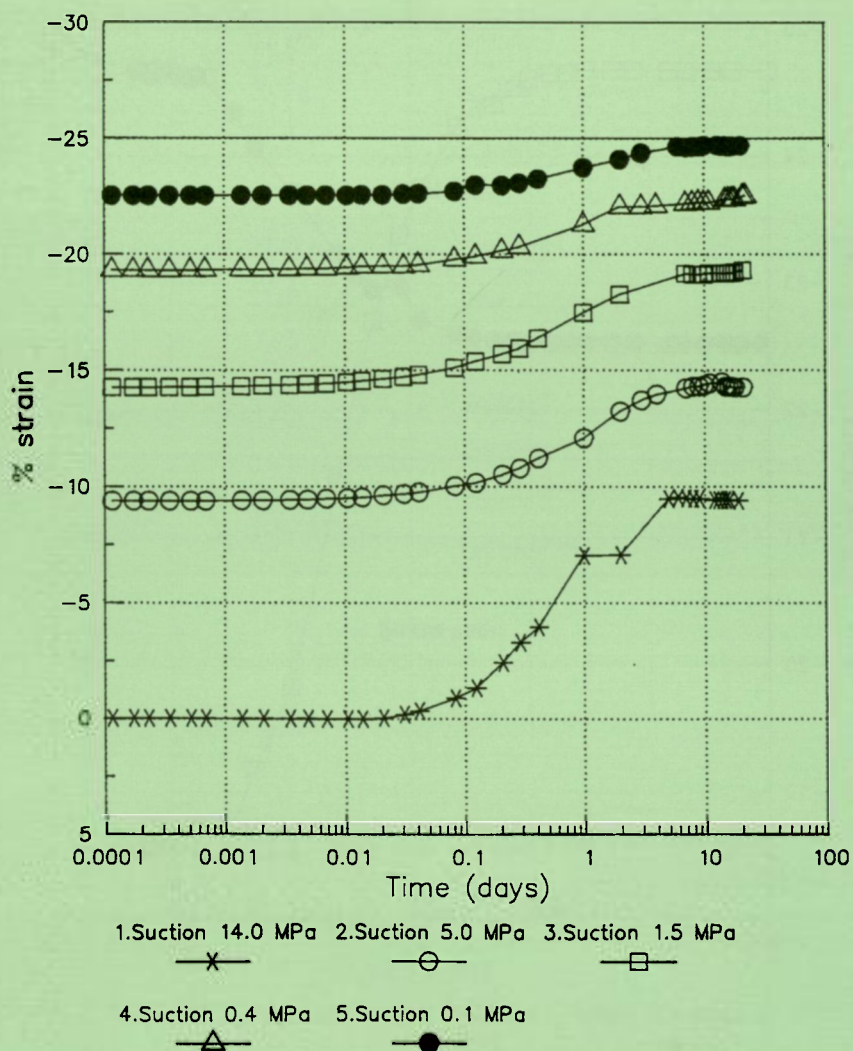


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN2_2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.5
1	0.1	14.0	0.6563	1.46	0.901	47.4
2	0.1	5.0	0.6855	1.41	0.986	49.3
3	0.1	1.5	0.7158	1.35	1.073	51.4
4	0.1	0.4	0.7351	1.31	1.129	52.7
5	0.1	0.1	0.7480	1.29	1.167	53.5
6	0.1	0.4	0.7115	1.36	1.061	51.2
7	0.1	1.5	0.7111	1.36	1.060	51.1

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN2_2

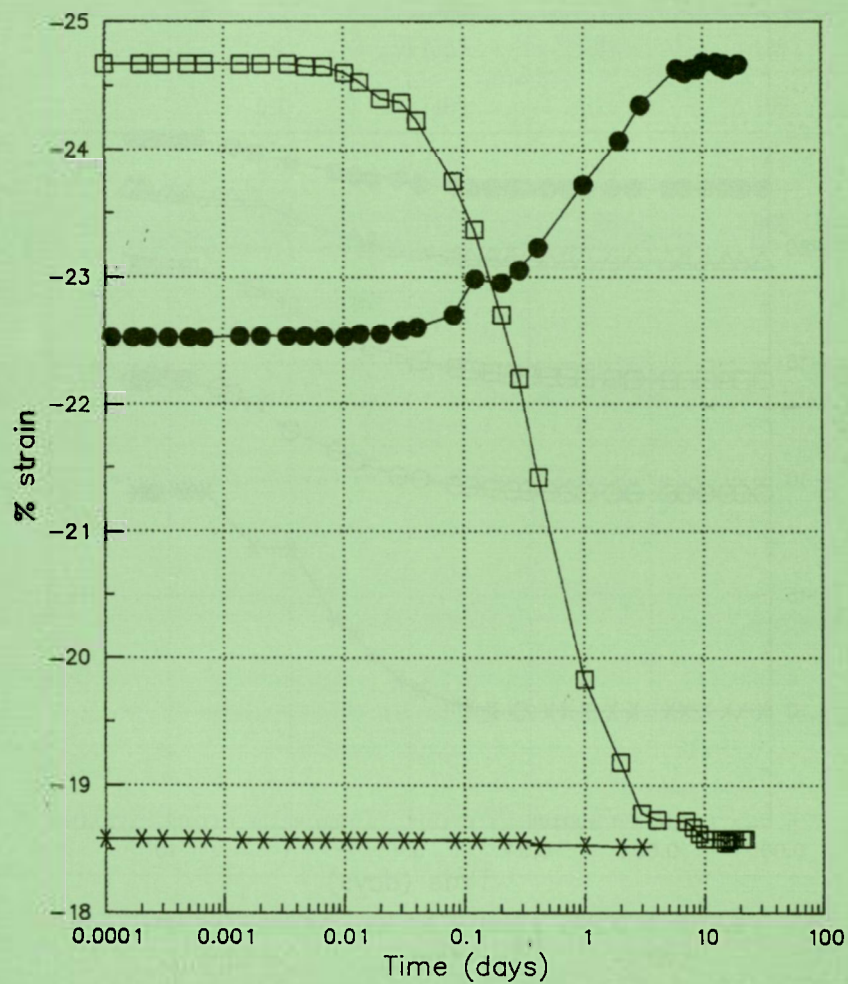
Initial dry density and w : 1.6 g/cm^3 , 11.0%



**Decreasing suction pressure
 at constant vertical load 0.1 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN2_2

Initial dry density and w: 1.6 g/cm³, 11.0%



5.Suction 0.1 MPa 6.Suction 1.5 MPa 7.Suction 14.0 MPa

—●— —□— —×—

Increasing suction pressure
at constant vertical load 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN3_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	18-1-94	End:	15-11-94

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

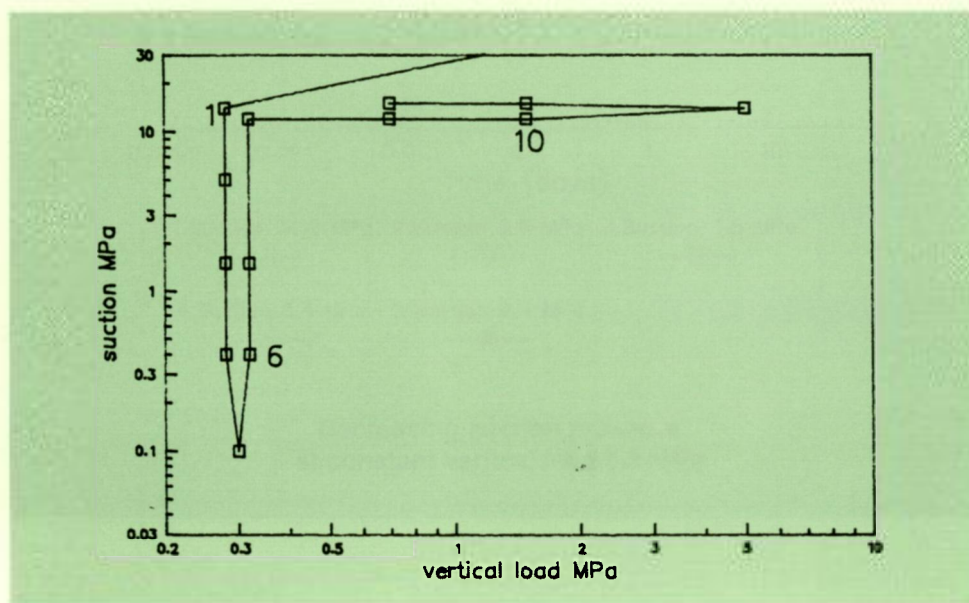
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.6 g	Assumed dry weight:	18.46 g
Water content:	11.6	Dry density:	1.60 g/cm ³

Final data

Weight:	22.67 g	Dry weight:	18.60 g
Water content:	21.9%	Initial dry density:	1.61 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.559 cm	Volume 1:	10.76 cm ³
		Dry dens. 1:	1.72 g/cm ³
Final h (deformation gauge:)	0.5839 cm	Volume 2:	11.23 cm ³
		Dry dens. 2:	1.65 g/cm ³

Stress path:

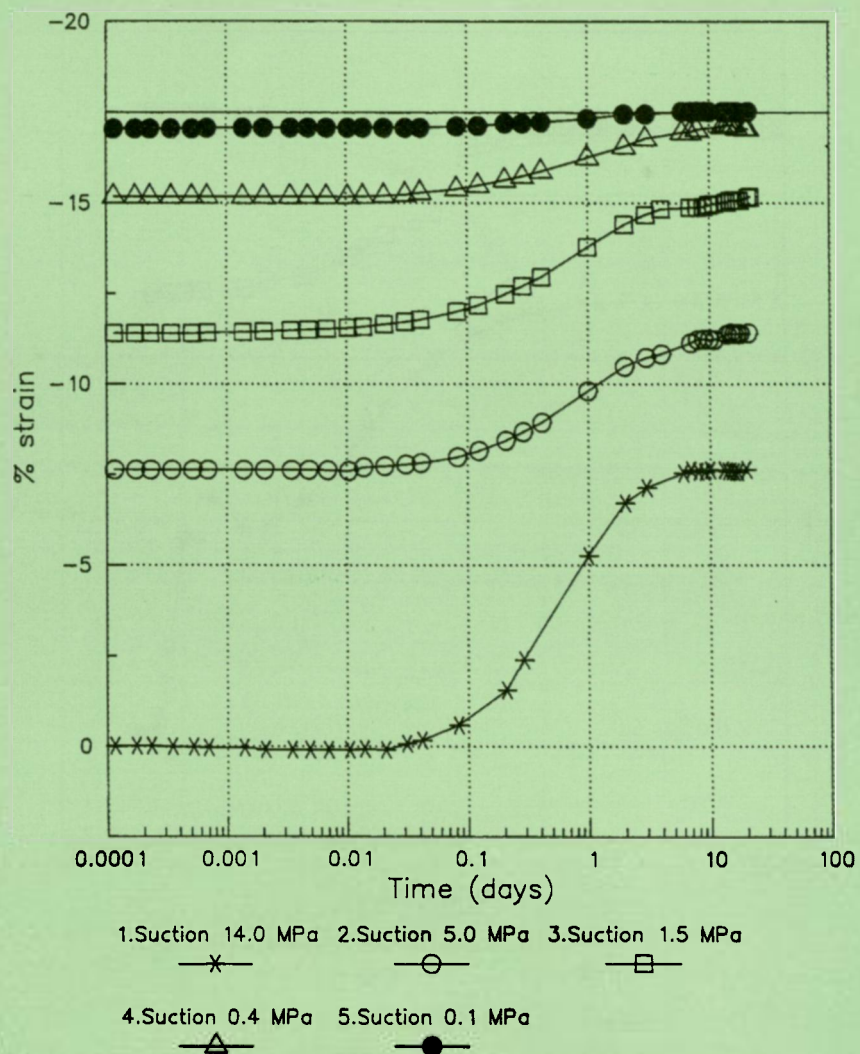


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN3_2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.3	14.0	0.6458	1.49	0.865	46.4
2	0.3	5.0	0.6684	1.45	0.9362	48.0
3	0.3	1.5	0.6910	1.40	1.002	49.7
4	0.3	0.4	0.7023	1.38	1.034	50.5
5	0.3	0.1	0.7051	1.37	1.0425	50.7
6	0.3	0.4	0.7025	1.38	1.0350	50.5
7	0.3	1.5	0.6706	1.44	0.9426	48.2
8	0.3	14.0	0.5908	1.64	0.7114	41.2
9	0.7	14.0	0.5905	1.64	0.7105	41.1
10	1.5	14.0	0.5738	1.68	0.6622	39.4
11	5.0	14.0	0.5621	1.72	0.6283	38.2
12	1.5	14.0	0.5645	1.71	0.6352	38.4
13	0.7	14.0	0.5839	1.65	0.6914	40.5

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN3_2

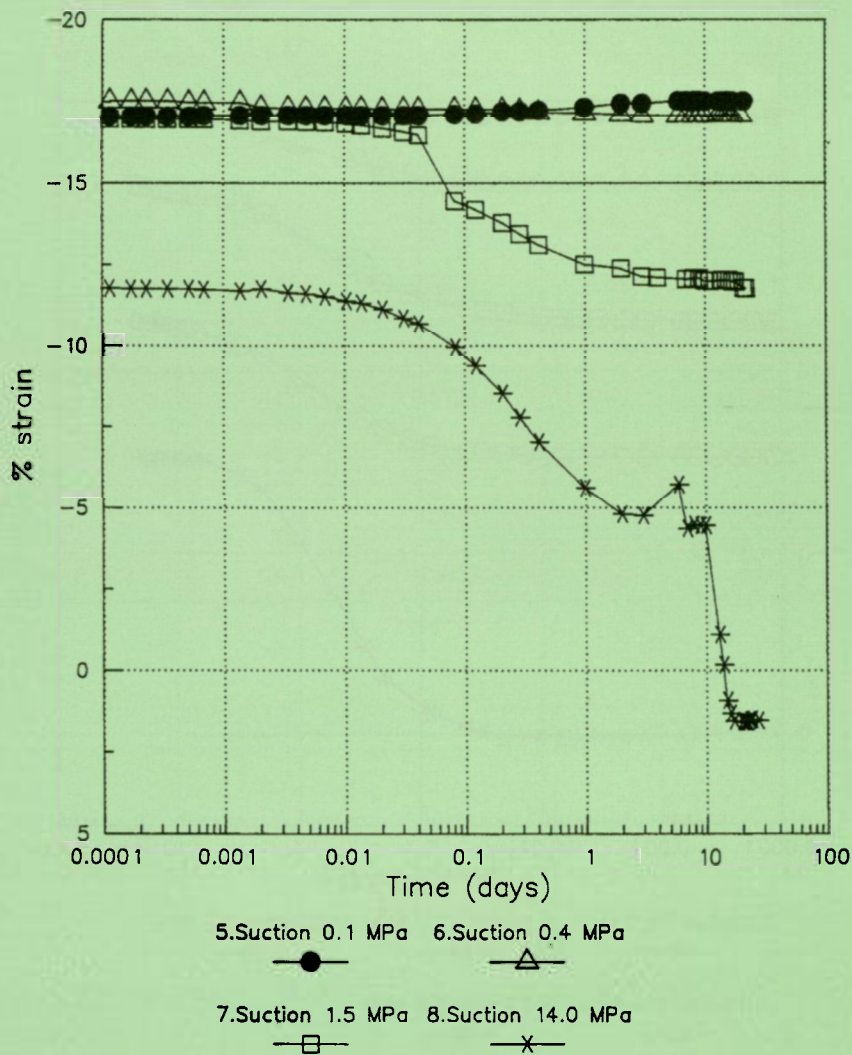
Initial dry density and w : 1.6 g/cm^3 , 11.6%



**Decreasing suction pressure
at constant vertical load 0.3 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN3_2

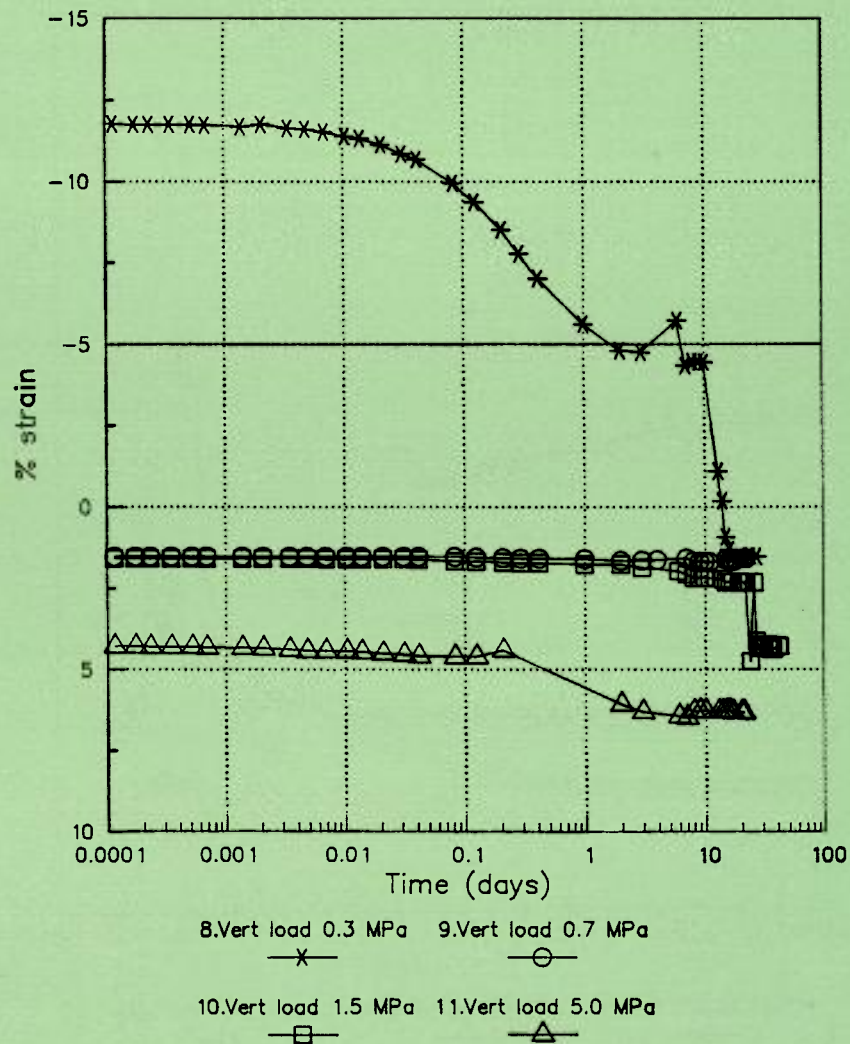
Initial dry density and w: 1.6 g/cm³, 11.6%



Increasing suction pressure
at constant vertical load 0.3 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN3_2

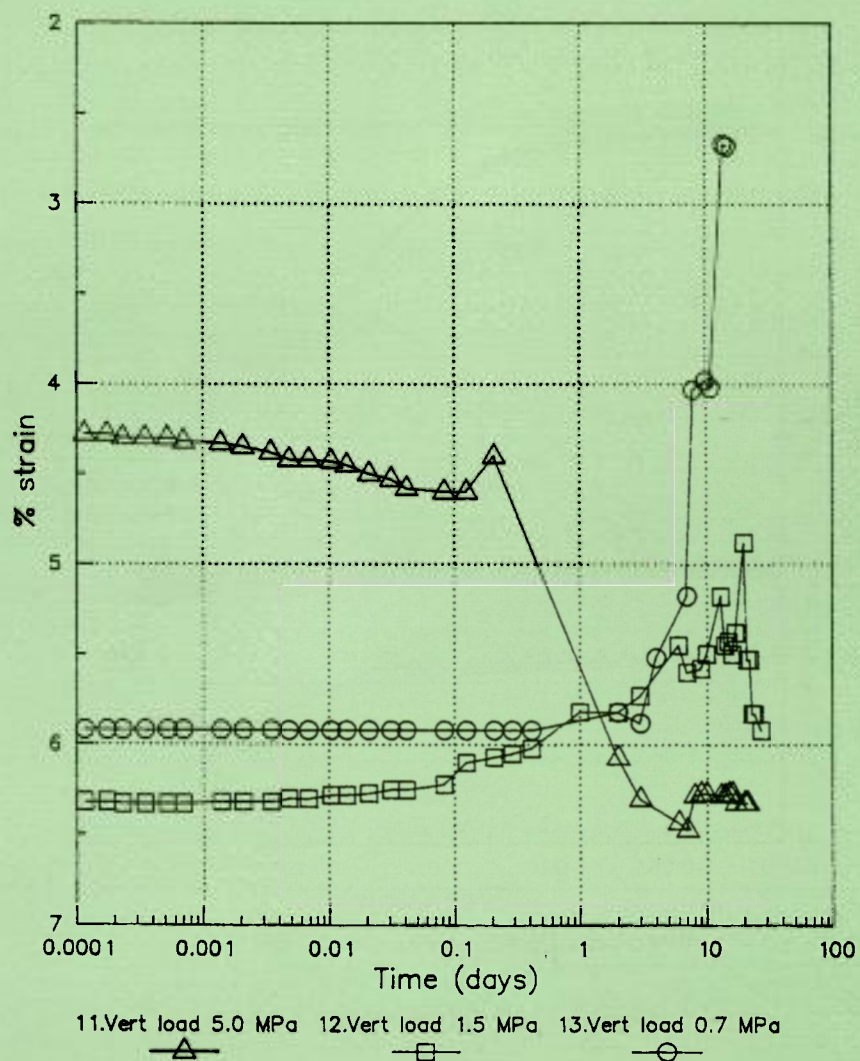
Initial dry density and w : 1.6 g/cm^3 , 11.6%



Loading at constant suction pressure 14.0 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN3_2

Initial dry density and w: 1.6 g/cm³, 11.6%



Unloading at constant suction pressure 14.0 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN4_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	15-3-94	End:	9-1-95

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

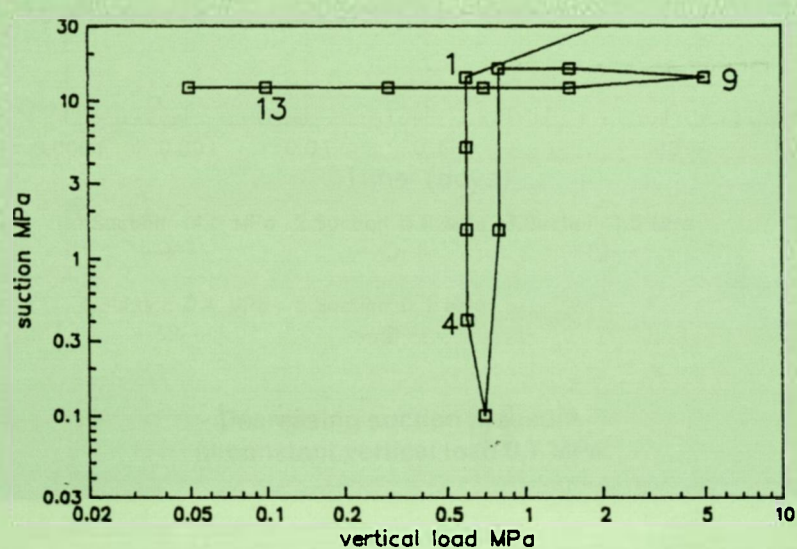
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.51 g	Assumed dry weight:	18.46 g
Water content:	11.1	Dry density:	1.60 g/cm ³

Final data

Weight:	22.57 g	Dry weight:	18.35 g
Water content:	23.0%	Initial dry density:	1.59 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.596 cm	Volume 1:	11.47 cm ³
		Dry dens. 1:	1.61 g/cm ³
Final h (deformation gauge:)	0.592 cm	Volume 2:	13.39 cm ³
		Dry dens. 2:	1.62 g/cm ³

Stress path:

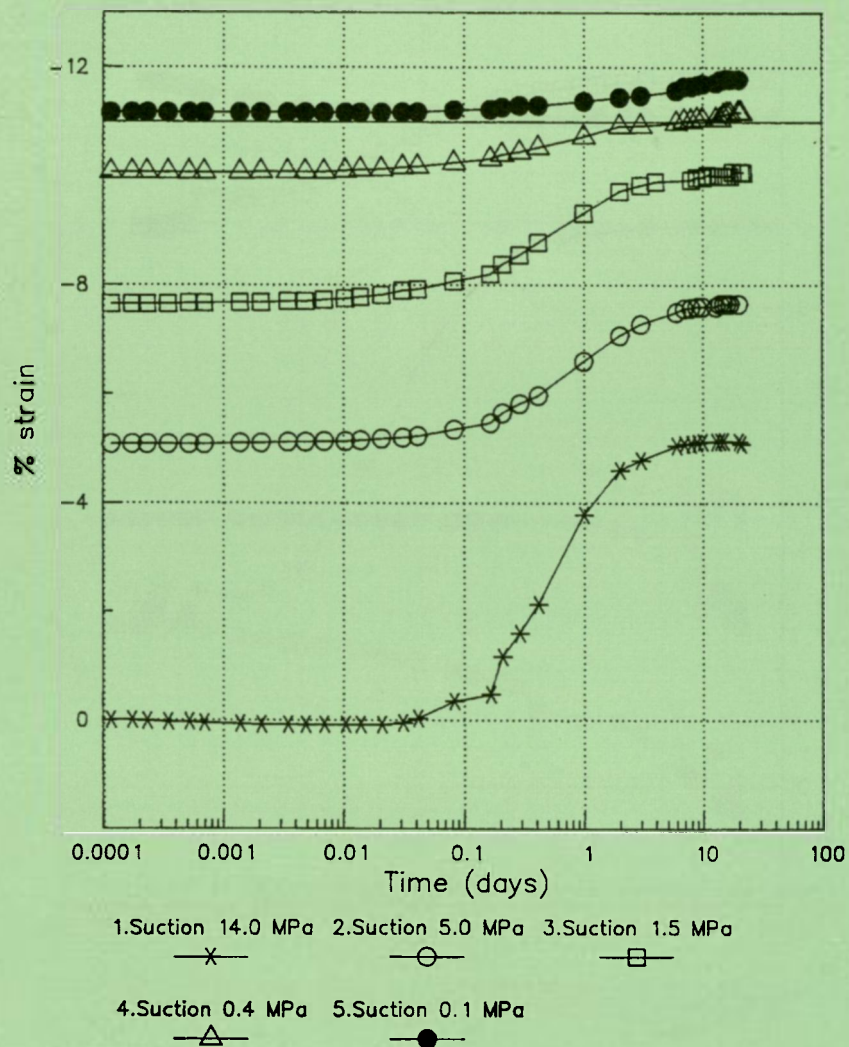


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN4 2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.737	42.4
1	0.07	14.0	0.6305	1.53	0.8264	44.9
2	0.07	5.0	0.6459	1.50	0.8710	46.2
3	0.07	1.5	0.6604	1.46	0.9130	47.4
4	0.07	0.4	0.6670	1.45	0.9321	47.9
5	0.07	0.1	0.6707	1.44	0.9429	48.2
6	0.07	1.5	0.6561	1.47	0.9006	47.0
7	0.07	14.0	0.6160	1.57	0.7844	43.6
8	1.5	14.0	0.6047	1.60	0.7517	42.5
9	5.0	14.0	0.5847	1.65	0.6937	40.6
10	1.5	14.0	0.5882	1.64	0.7039	40.9
11	0.7	14.0	0.5885	1.64	0.7047	40.9
12	0.3	14.0	0.5908	1.64	0.7114	41.2
13	0.1	14.0	0.5914	1.63	0.7132	41.2
14	0.05	14.0	0.5920	1.63	0.7149	41.3

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN4_2

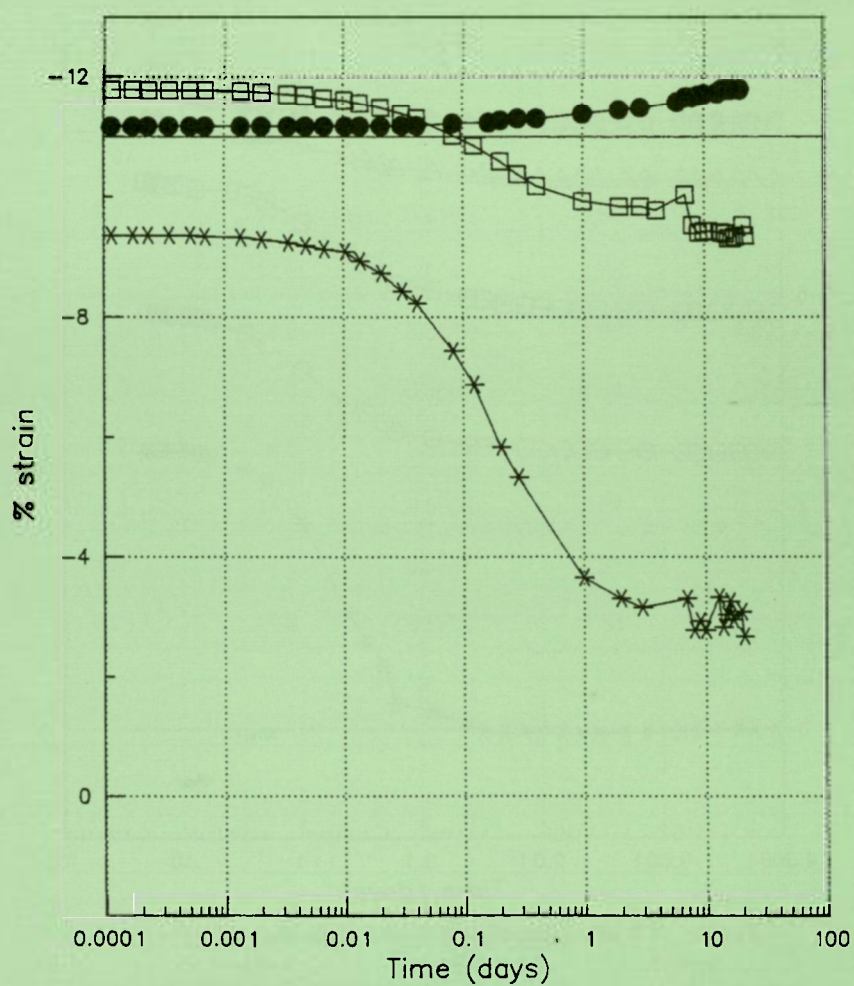
Initial dry density and w : 1.6 g/cm^3 , 11.1%



**Decreasing suction pressure
at constant vertical load 0.7 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN4_2

Initial dry density and w: 1.6 g/cm³, 11.1%



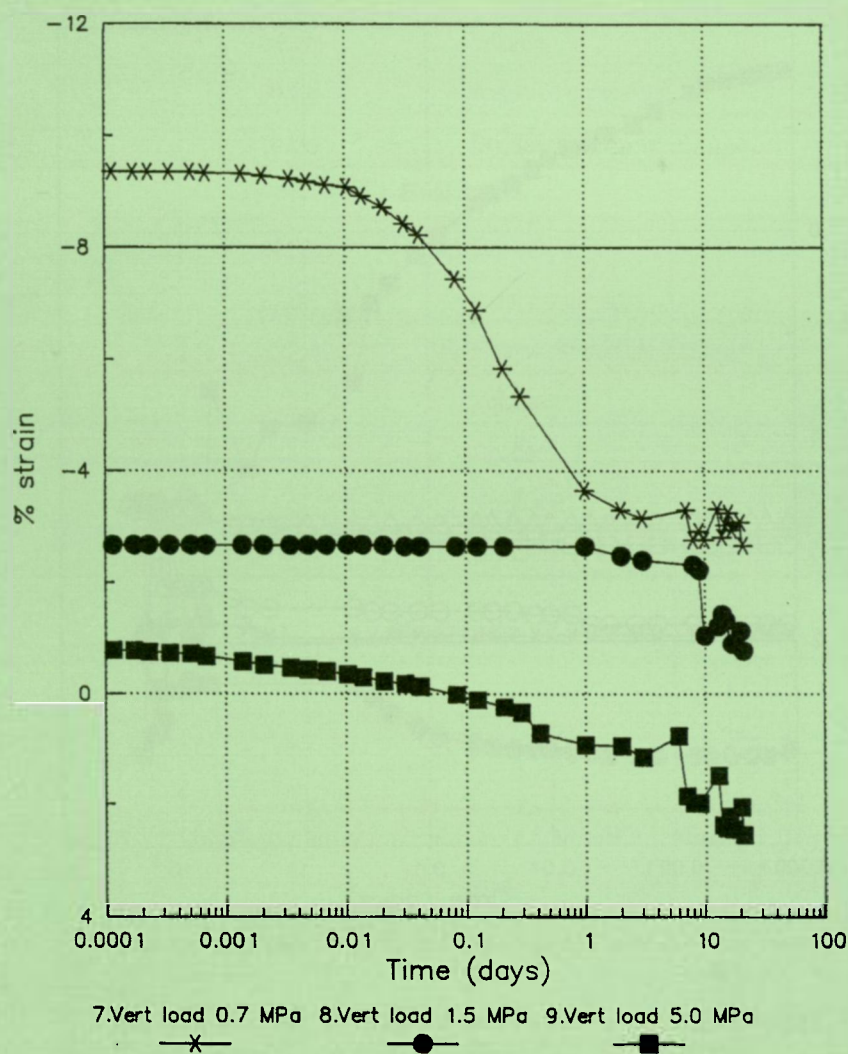
5.Suction 0.1 MPa 6.Suction 1.5 MPa 7.Suction 14.0 MPa

—●— —□— —×—

**Increasing suction pressure
at constant vertical load 0.7 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN4_2

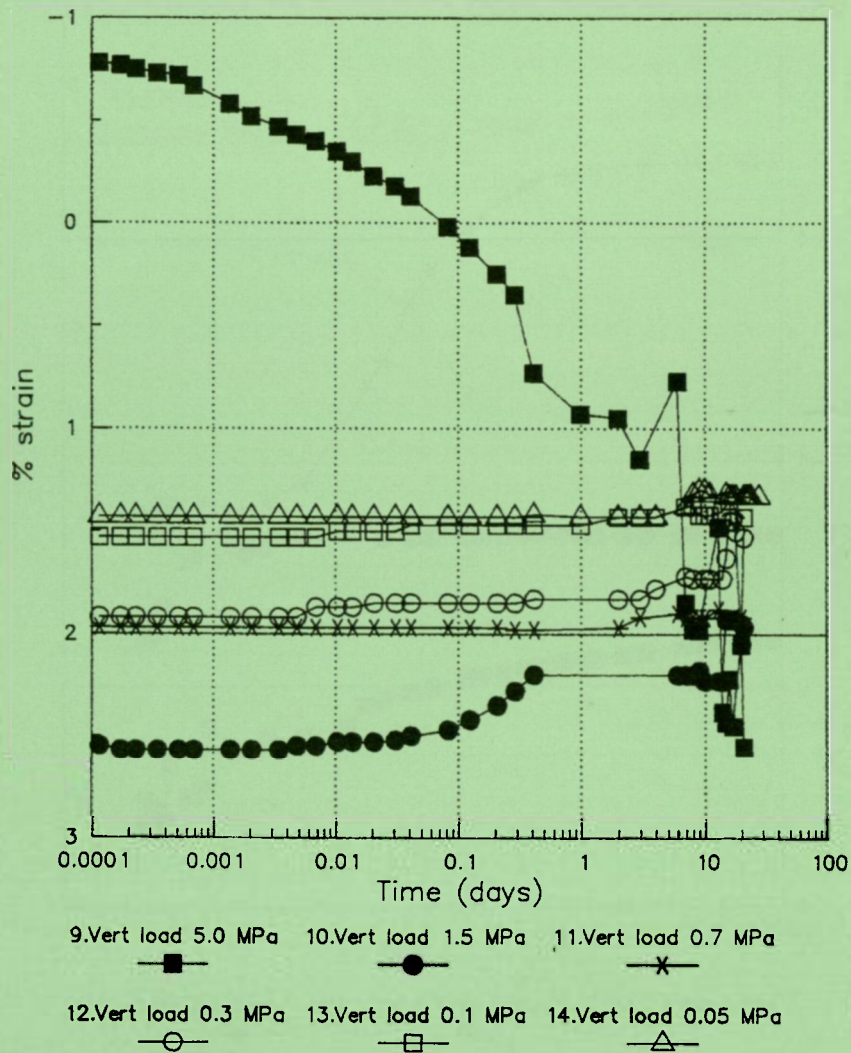
Initial dry density and w : 1.6 g/cm³, 11.1%



Loading at constant suction pressure 14.0 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN4_2

Initial dry density and w: 1.6 g/cm³, 11.1%



Unloading at constant suction pressure 14.0 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. NITROGEN

Reference:	EDN5_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	25-1-94	End:	21-11-94

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

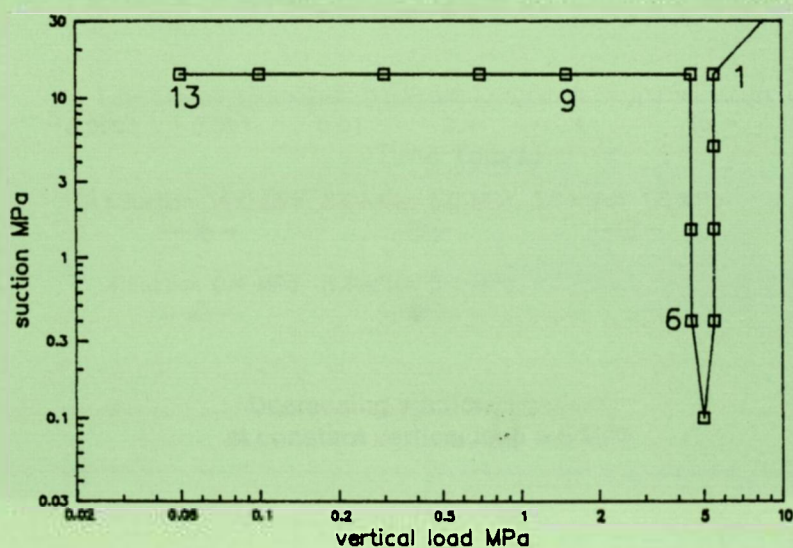
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.6 g	Assumed dry weight:	18.59 g
Water content:	10.8%	Dry density:	1.61 g/cm ³

Final data

Weight:	22.53 g	Dry weight:	18.50 g
Water content:	21.8%	Initial dry density:	1.60 g/cm ³
Uptake water:		Final water content 2:	
Final h (average 4 measures):	0.585 cm	Volume 1:	11.25 cm ³
		Dry dens. 1:	1.64 g/cm ³
Final h (deformation gauge:)	0.5907 cm	Volume 2:	11.36 cm ³
		Dry dens. 2:	1.64 g/cm ³

Stress path:

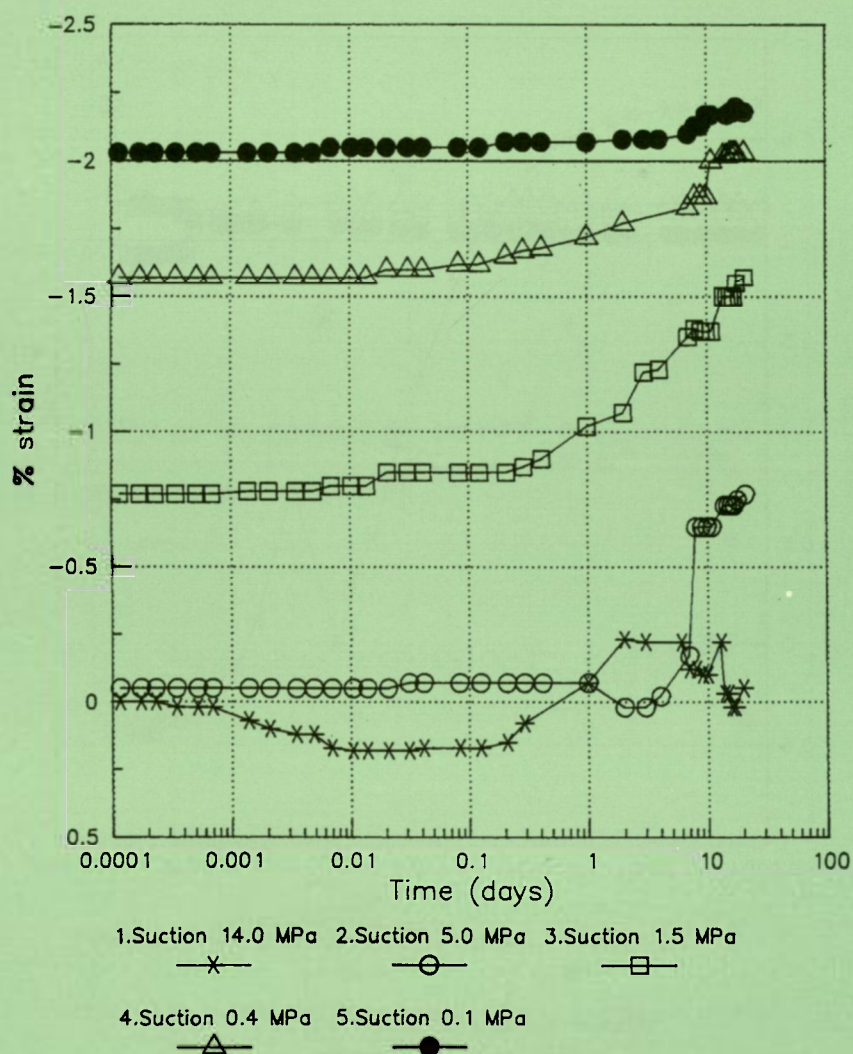


SUCTION CONTROLLED OEDOMETERS. NITROGEN. EDN5_2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.61	0.727	42.1
1	5.0	14.0	0.6003	1.61	0.734	42.1
2	5.0	5.0	0.6046	1.60	0.751	42.5
3	5.0	1.5	0.6094	1.59	0.765	43.0
4	5.0	0.4	0.6122	1.58	0.773	43.2
5	5.0	0.1	0.6131	1.58	0.776	43.3
6	5.0	0.4	0.6129	1.58	0.775	43.3
7	5.0	1.5	0.6160	1.57	0.784	43.6
8	5.0	14.0	0.5973	1.62	0.730	41.8
9	1.5	14.0	0.5998	1.61	0.737	42.1
10	0.7	14.0	0.5871	1.65	0.701	40.8
11	0.3	14.0	0.5893	1.64	0.707	41.0
12	0.1	14.0	0.5900	1.64	0.709	41.1
13	0.05	14.0	0.5907	1.64	0.711	41.2

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN **Consolidation curves. Montmorillonite EDN5_2**

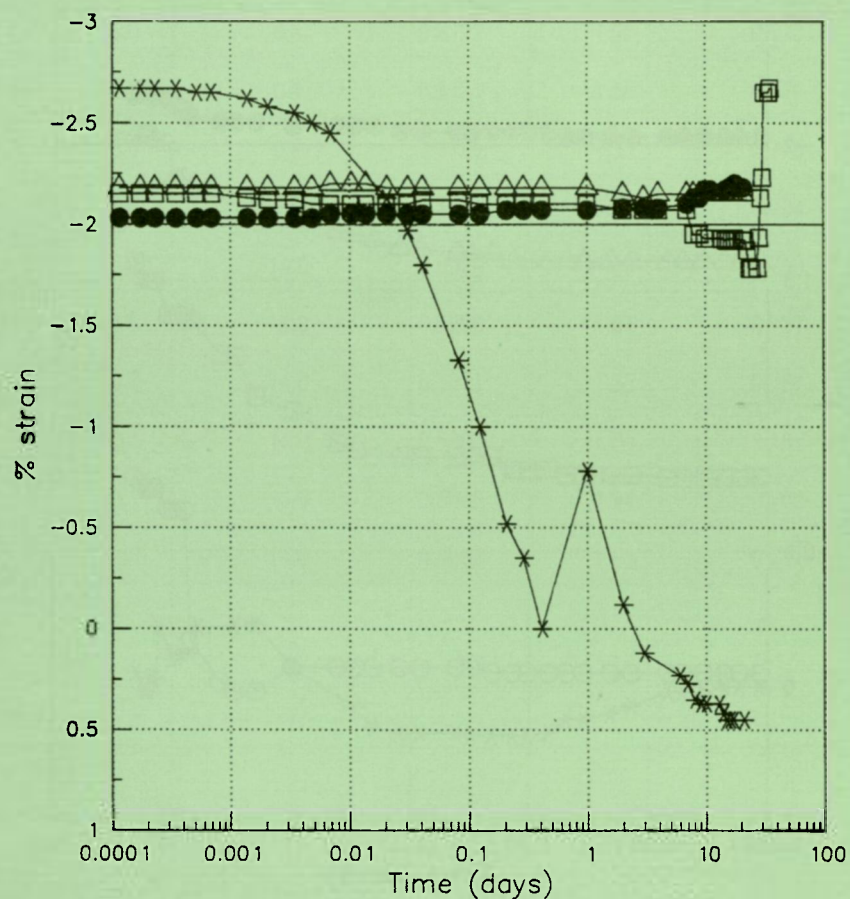
Initial dry density and w : 1.6 g/cm^3 , 10.8%



**Decreasing suction pressure
at constant vertical load 5.0 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN5_2

Initial dry density and w: 1.6 g/cm³, 10.8%



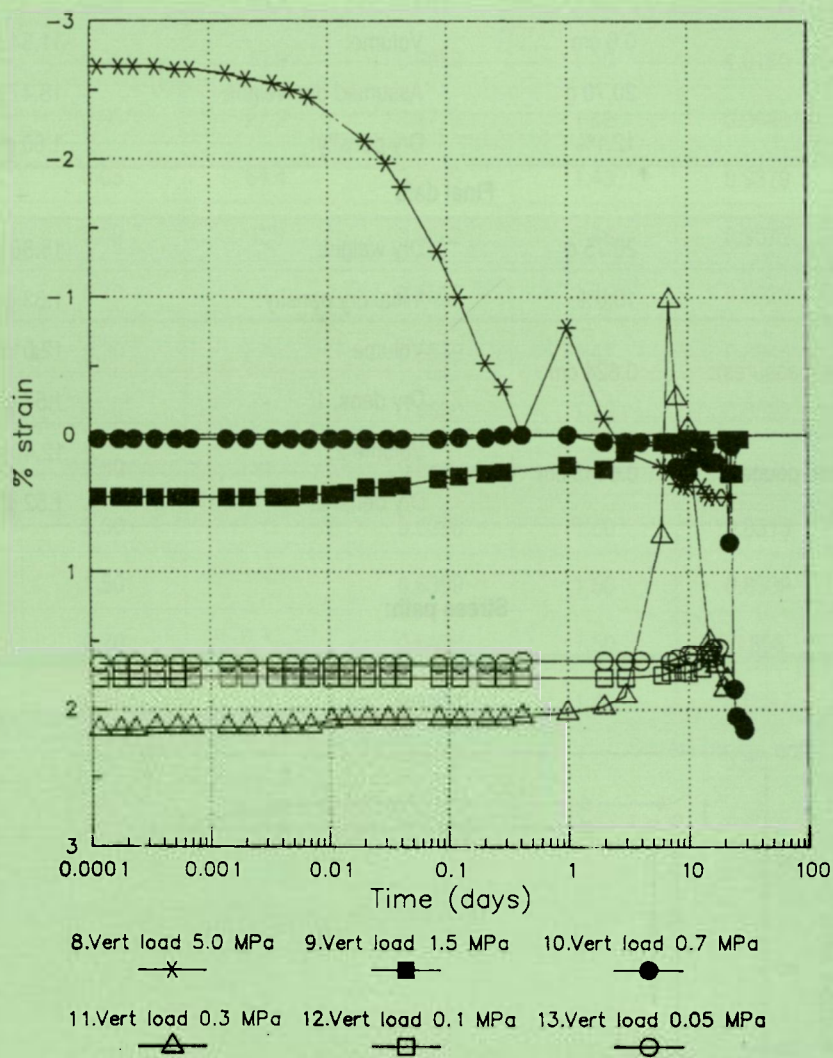
5.Suction 0.1 MPa 6.Suction 0.4 MPa

7.Suction 1.5 MPa 8.Suction 14.0 MPa

**Increasing suction pressure
at constant vertical load 5.0 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. NITROGEN
Consolidation curves. Montmorillonite EDN5_2

Initial dry density and w: 1.6 g/cm³, 10.8%



Unloading at constant suction pressure 14.0 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS1_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	22-11-93	End:	

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

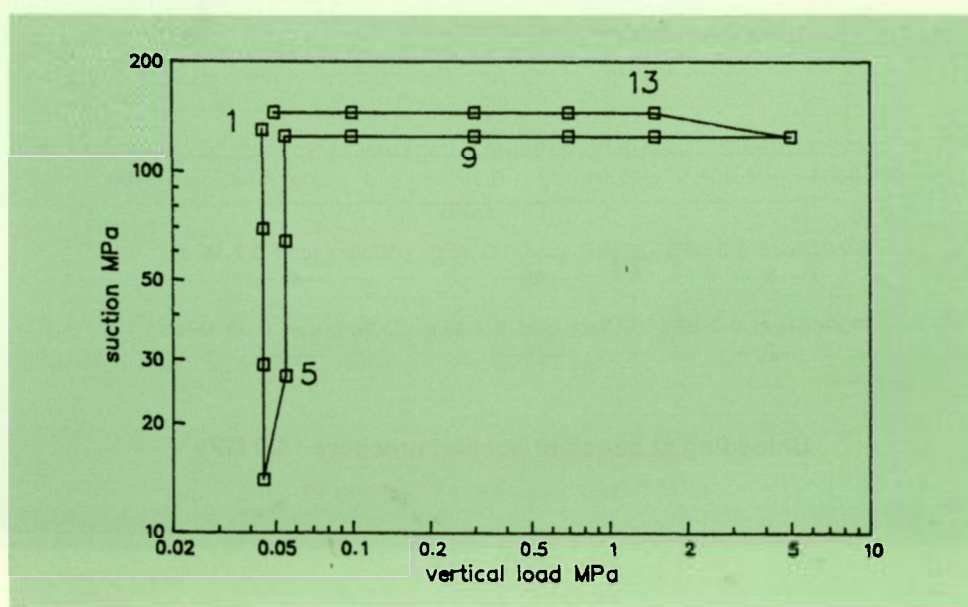
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.70 g	Assumed dry weight:	18.47 g
Water content:	12.1%	Dry density:	1.60 g/cm ³

Final data

Weight:	20.75 g	Dry weight:	18.86 g
Water content:	10.0%	Initial dry density:	1.63 g/cm ³
Final h (average 4 measures):	0.624 cm	Volume 1:	12.01 cm ³
		Dry dens. 1:	1.57 g/cm ³
Final h (deformation gauge:)	0.6443 cm	Volume 2:	12.40 cm ³
		Dry dens. 2:	1.52 g/cm ³

Stress path:

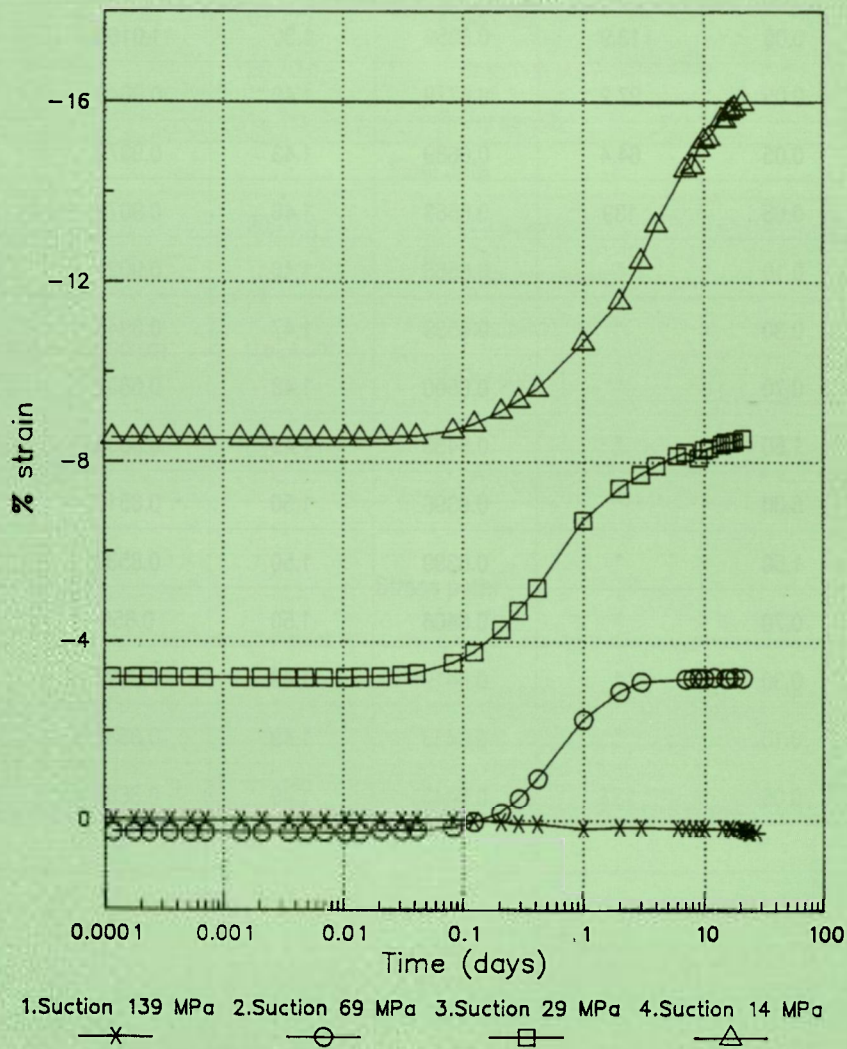


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS1_2

Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.7370	42.4
1	0.05	139.4	0.5984	1.60	0.7370	42.3
2	0.05	69.5	0.6192	1.55	0.7940	44.3
3	0.05	28.8	0.6512	1.47	0.8870	47.0
4	0.05	13.9	0.6959	1.30	1.0160	50.4
5	0.05	27.2	0.6779	1.42	0.9640	49.1
6	0.05	64.4	0.6689	1.43	0.9379	48.4
7	0.05	139	0.6583	1.46	0.9072	47.6
8	0.10	"	0.6566	1.46	0.9023	47.4
9	0.30	"	0.6539	1.47	0.8945	47.2
10	0.70	"	0.6500	1.48	0.8832	46.9
11	1.50	"	0.6453	1.49	0.8696	46.5
12	5.00	"	0.6390	1.50	0.8513	46.0
13	1.50	"	0.6399	1.50	0.8539	46.1
14	0.70	"	0.6406	1.50	0.856	46.1
15	0.30	"	0.6419	1.49	0.8597	46.2
16	0.10	"	0.6433	1.49	0.8638	46.3
17	0.05	137	0.6443	1.49	0.8667	46.4

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS1_2

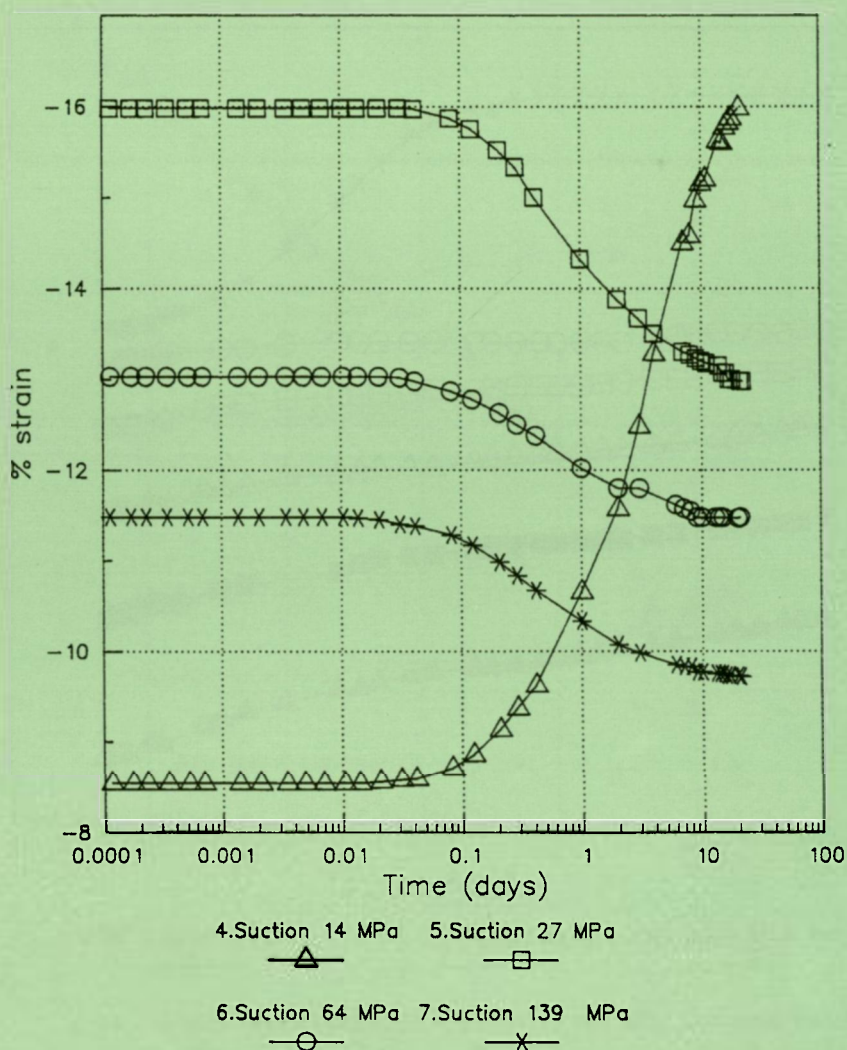
Initial dry density 1.6 g/cm^3 , initial w 12.1%



**Decreasing suction pressure
at constant vertical load 0.05 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS1_2

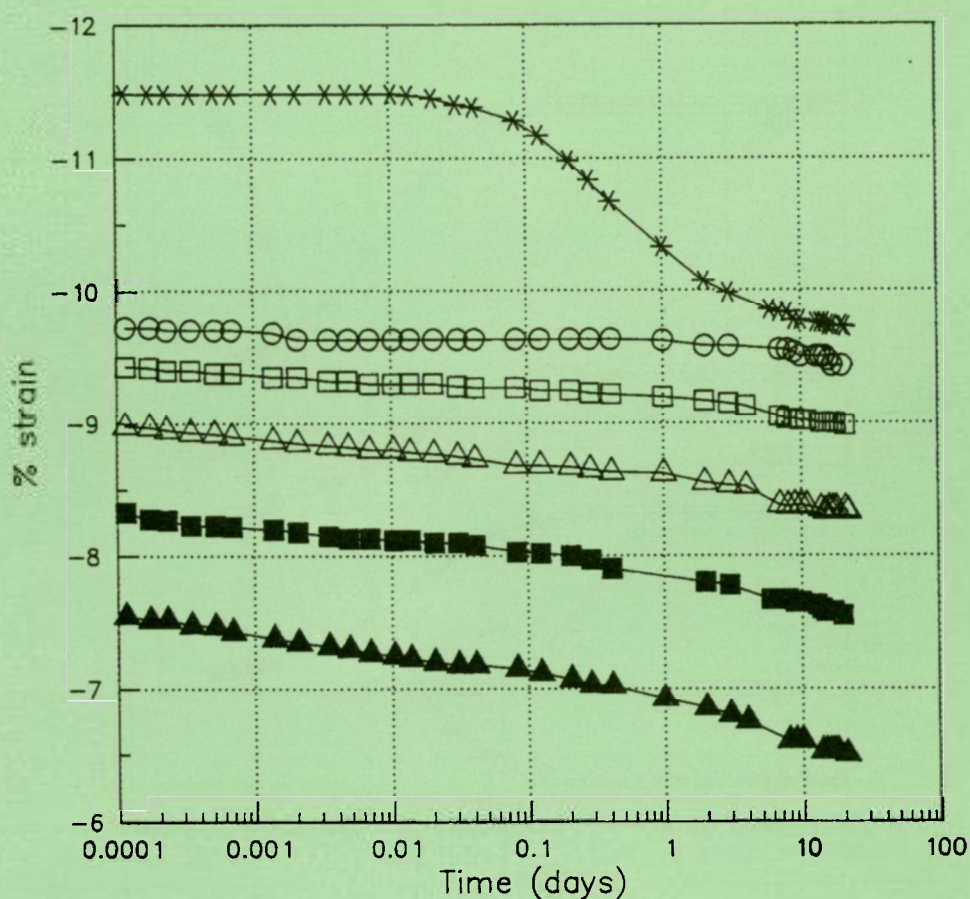
Initial dry density 1.6 g/cm³, initial w 12.1%



**Increasing suction pressure
 at constant vertical load 0.05 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS1_2

Initial dry density 1.6 g/cm³, initial w 12.1%

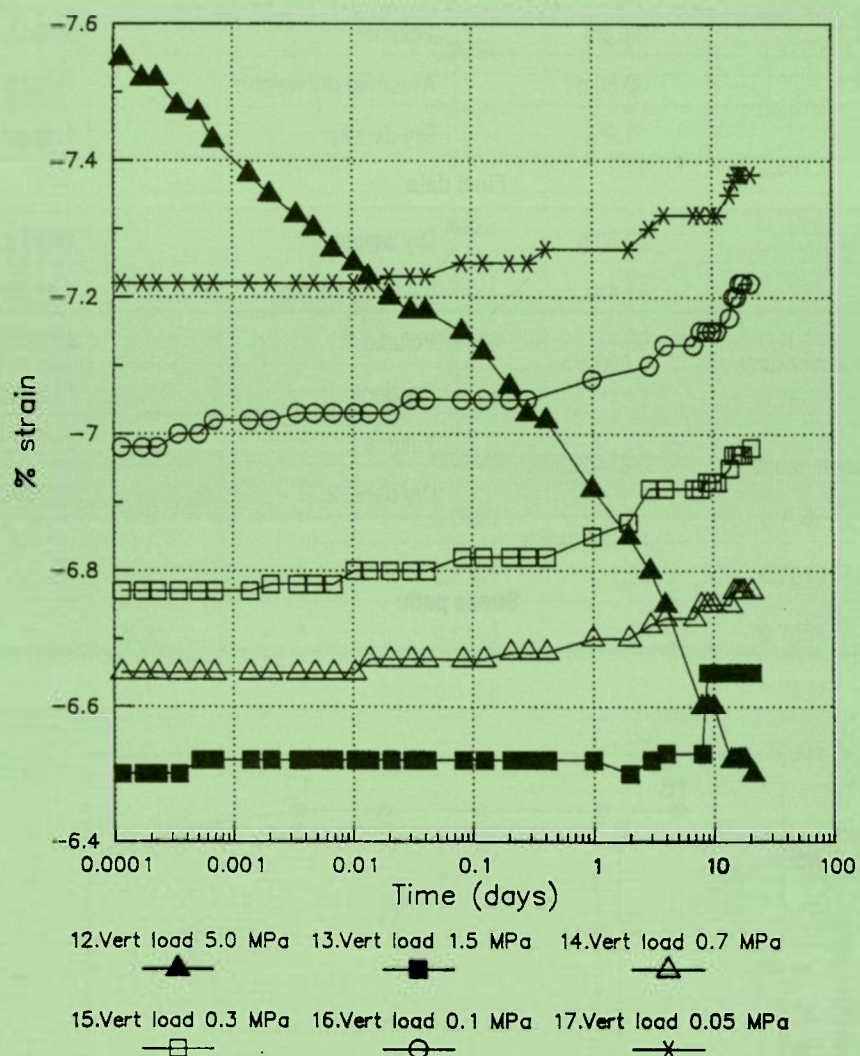


7.Vert load 0.05 MPa 8.Vert load 0.1 MPa 9.Vert load 0.3 MPa
 10.Vert load 0.7 MPa 11.Vert load 1.5 MPa 12.Vert load 5.0 MPa

Increasing vertical load
at constant suction pressure 139 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS1_2

Initial dry density 1.6 g/cm³, initial w 12.1%



Decreasing vertical load
at constant suction pressure 137 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS2_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	29-11-93	End:	

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

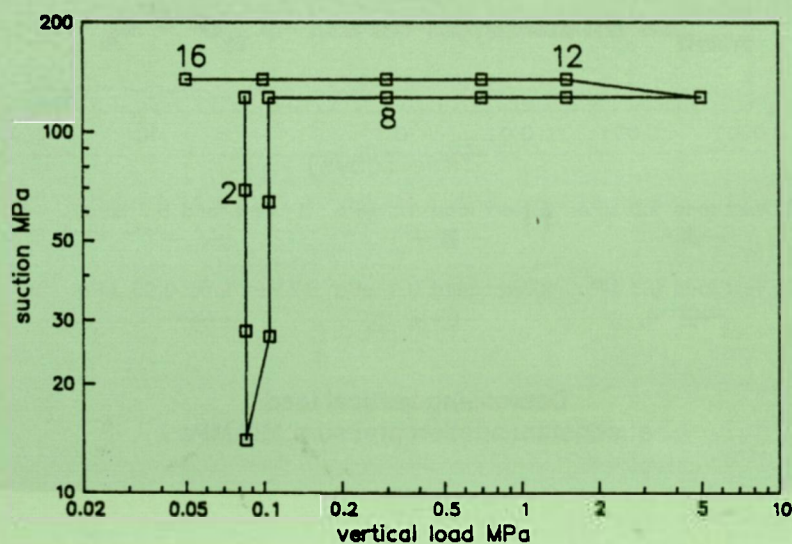
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.60 g	Assumed dry weight:	18.52 g
Water content:	11.2%	Dry density:	1.60 g/cm ³

Final data

Weight:	20.68 g	Dry weight:	18.56 g
Water content:	11.4%	Initial dry density:	1.61 g/cm ³
Final h (average 4 measures):	0.602 cm	Volume 1:	11.58 cm ³
		Dry dens. 1:	1.60 g/cm ³
Final h (deformation gauge:)	0.6140 cm	Volume 2:	11.81 cm ³
		Dry dens. 2:	1.57 g/cm ³

Stress path:

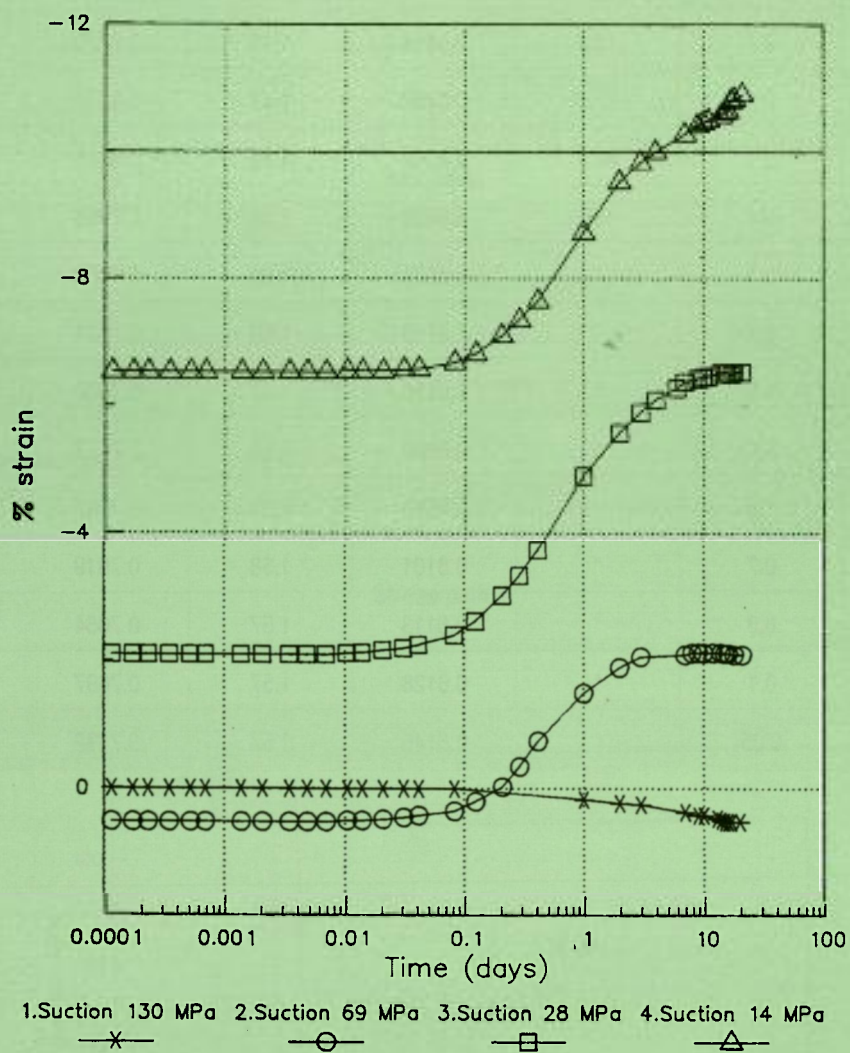


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS2_2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.7370	42.4
1	0.1	130.2	0.5969	1.61	0.7238	42.0
2	0.1	69.0	0.6126	1.57	0.7691	43.5
3	0.1	28.4	0.6392	1.50	0.8459	45.9
4	0.1	13.9	0.6654	1.45	0.9220	48.0
5	0.1	27.0	0.6466	1.49	0.8670	46.5
6	0.1	64.4	0.6342	1.52	0.8315	45.4
7	0.1	139	0.6228	1.54	0.7986	44.5
8	0.3	"	0.6201	1.55	0.7908	44.2
9	0.7	"	0.6165	1.56	0.7804	43.9
10	1.5	"	0.6116	1.57	0.7662	43.4
11	5.0	"	0.6050	1.59	0.7472	42.8
12	1.5	"	0.6083	1.58	0.7567	43.1
13	0.7	"	0.6101	1.58	0.7619	43.3
14	0.3	"	0.6113	1.57	0.7654	43.4
15	0.1	"	0.6128	1.57	0.7697	43.5
16	0.05	"	0.6140	1.57	0.7732	43.7

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS2_2

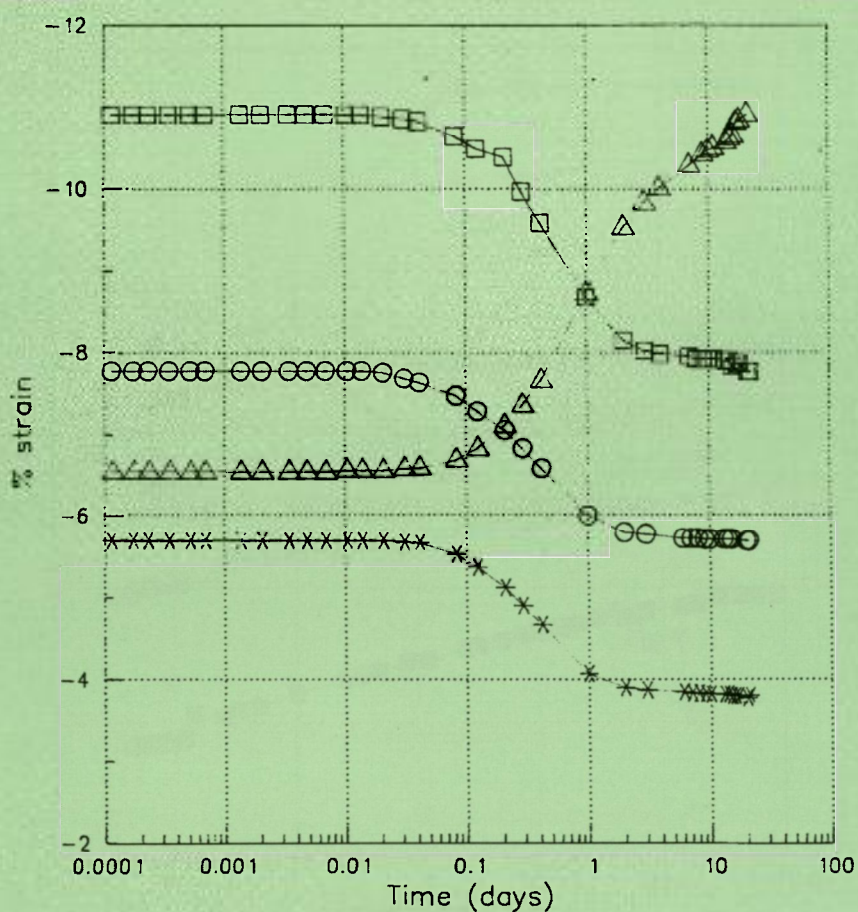
Initial dry density 1.6 g/cm³, initial w 12.1%



**Decreasing suction pressure
at constant vertical load 0.1 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS2_2

Initial dry density 1.6 g/cm³, initial w 12.1%

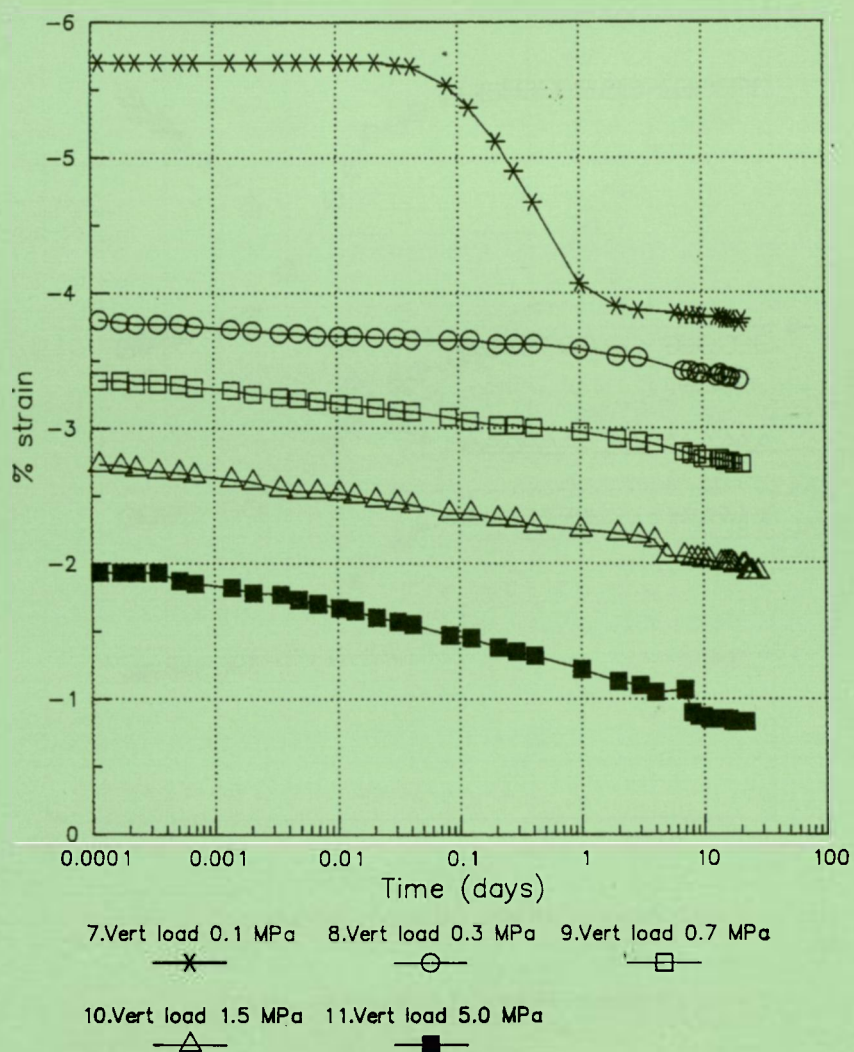


4.Suction 14 MPa 5.Suction 27 MPa
 —△— —□—
 6.Suction 64 MPa 7.Suction 139 MPa
 —○— —*—

Increasing suction pressure
at constant vertical load 0.1 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS2_2

Initial dry density 1.6 g/cm^3 , initial w 12.1%

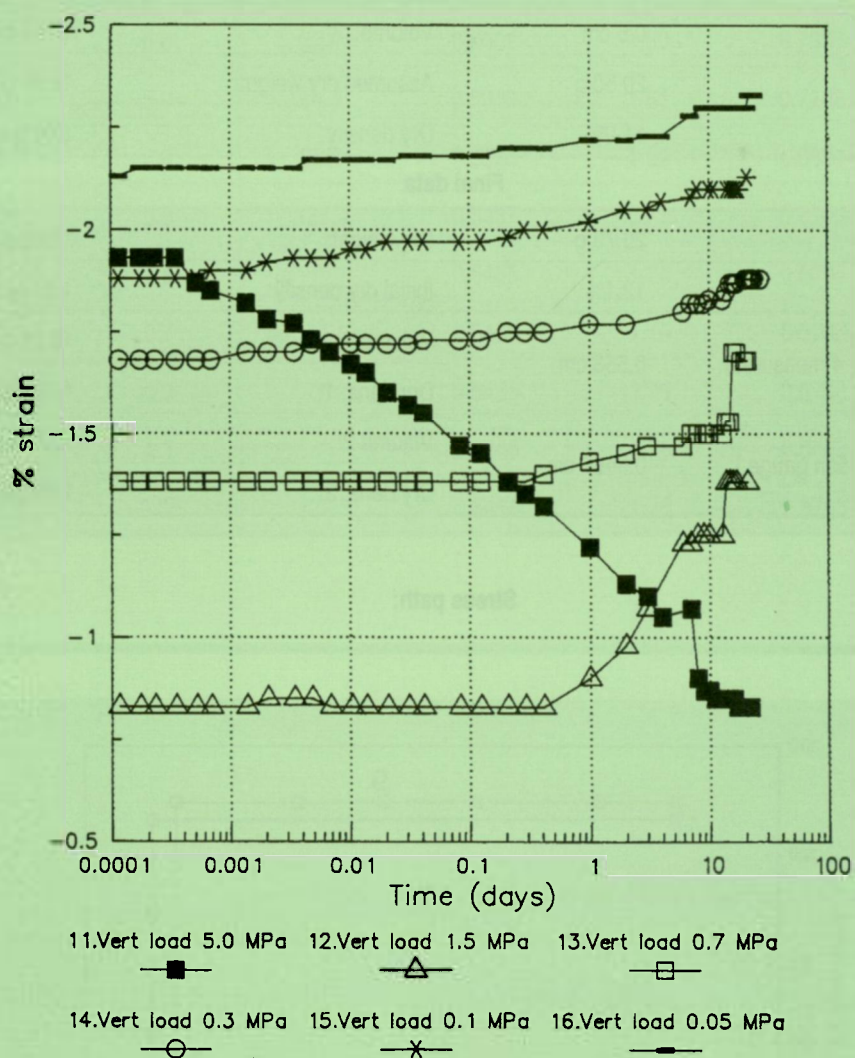


Increasing vertical load
at constant suction pressure 139 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC

Consolidation curves. Montmorillonite EDS2_2

Initial dry density 1.6 g/cm³, initial w 12.1%



Decreasing vertical load
at constant suction pressure 137 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS3_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	22-2-94	End:	3-11-94

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

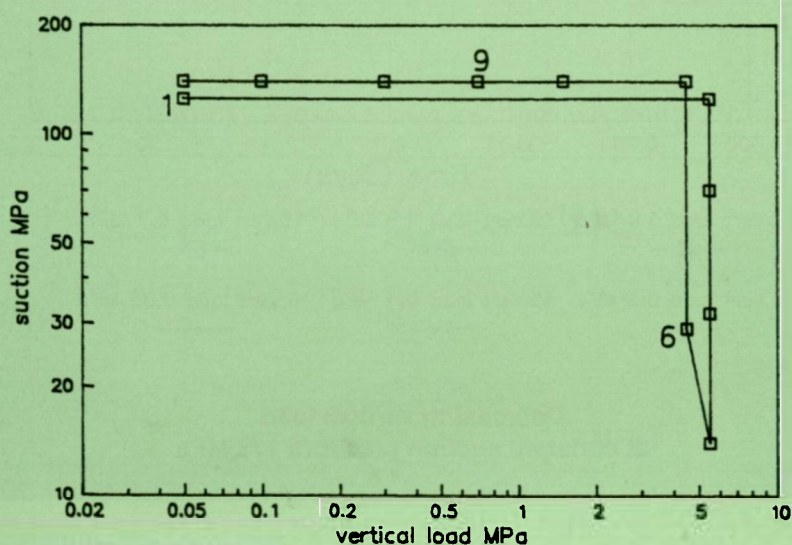
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.50 g	Assumed dry weight:	18.47 g
Water content:	11.0%	Dry density:	1.60 g/cm ³

Final data

Weight:	20.73 g	Dry weight:	18.49 g
Water content:	12.1%	Initial dry density:	1.60 g/cm ³
Final h (average 4 measures):	0.558 cm	Volume 1:	10.73 cm ³
		Dry dens. 1:	1.72 g/cm ³
Final h (deformation gauge:)	0.5466 cm	Volume 2:	10.52 cm ³
		Dry dens. 2:	1.76 g/cm ³

Stress path:

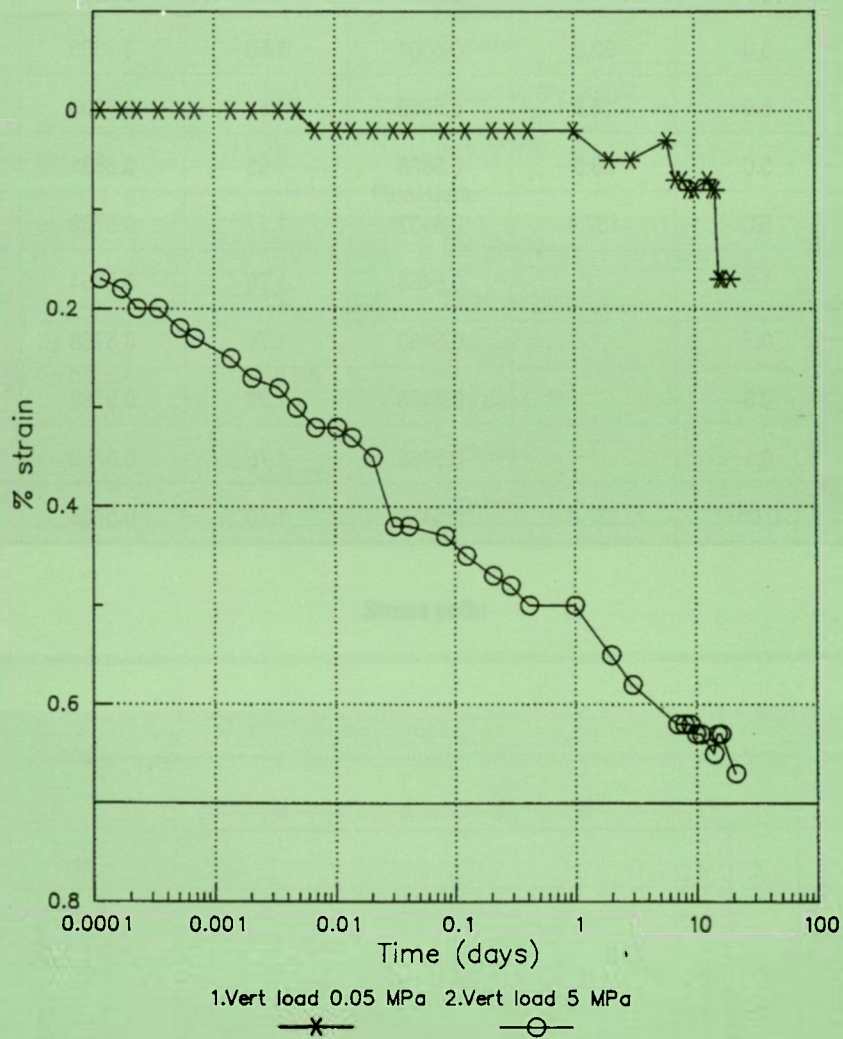


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS3_2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.7370	42.4
1	0.05	134.7	0.5940	1.61	0.7299	42.2
2	5.0	138.2	0.5960	1.61	0.7212	42.0
3	5.0	70.3	0.5996	1.60	0.7316	42.3
4	5.0	32.2	0.6001	1.60	0.7330	42.3
5	5.0	14.5	0.5959	1.61	0.7209	41.9
6	5.0	28.6	0.5828	1.65	0.6831	40.6
7	5.0	137.4	0.5437	1.77	0.5702	36.4
8	1.5	"	0.5455	1.76	0.5754	36.6
9	0.7	"	0.5460	1.76	0.5768	36.6
10	0.3	"	0.5466	1.76	0.5768	36.6
11	0.1	"	0.5465	1.76	0.5768	36.6
12	0.05	127.3	0.5466	1.76	0.5768	36.6

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS3_2

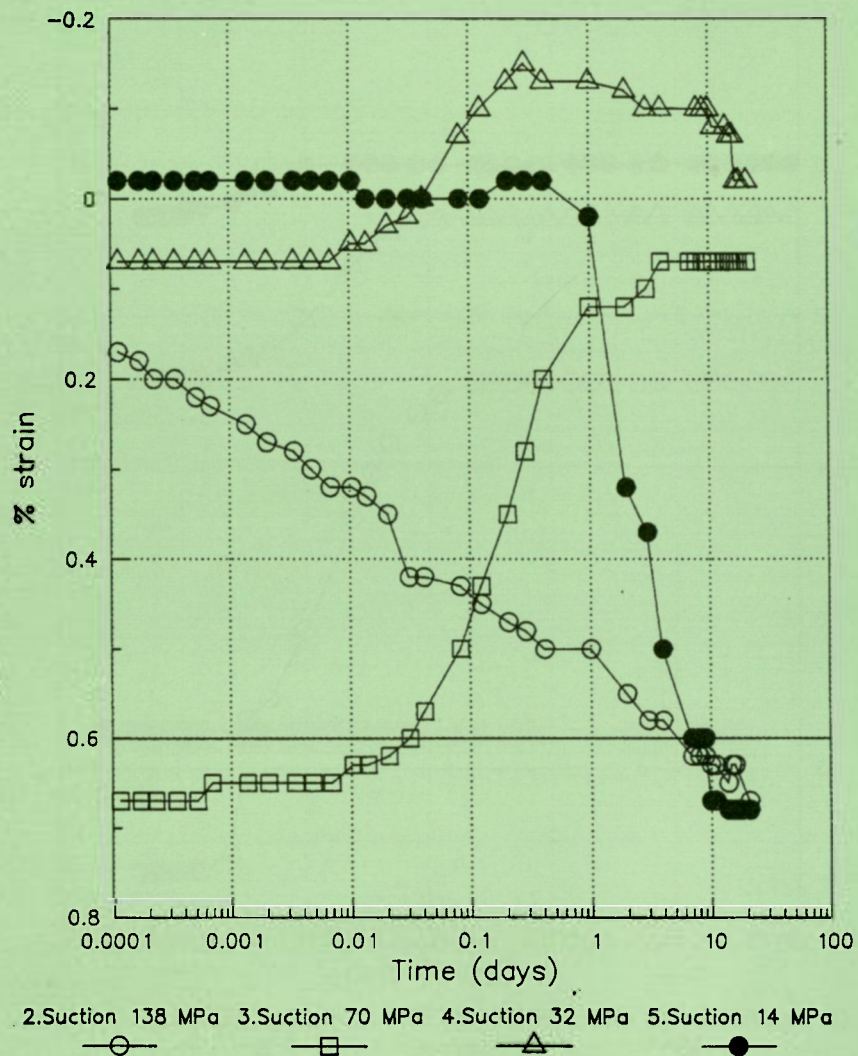
Initial dry density 1.6 g/cm³, initial w 11.0%



**Increasing vertical load
 at constant suction pressure 138 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS3_2

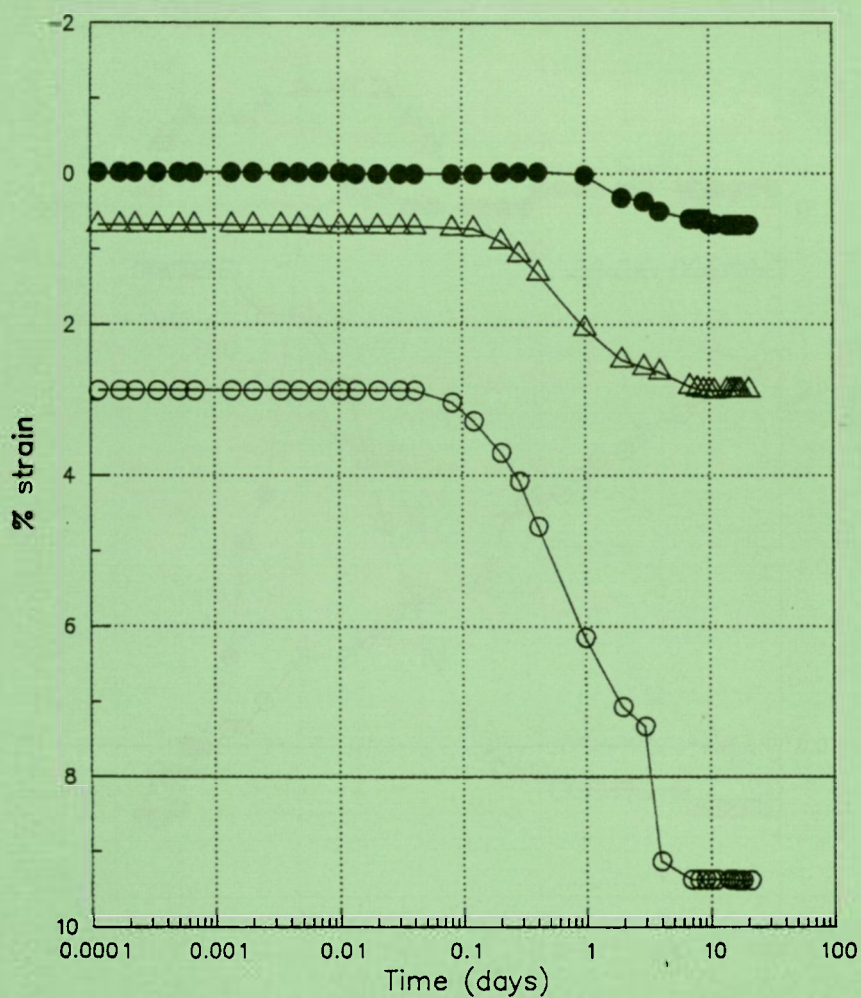
Initial dry density 1.6 g/cm^3 , initial w 11.0%



**Decreasing suction pressure
at constant vertical load 5 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS3_2

Initial dry density 1.6 g/cm^3 , initial w 11.0%

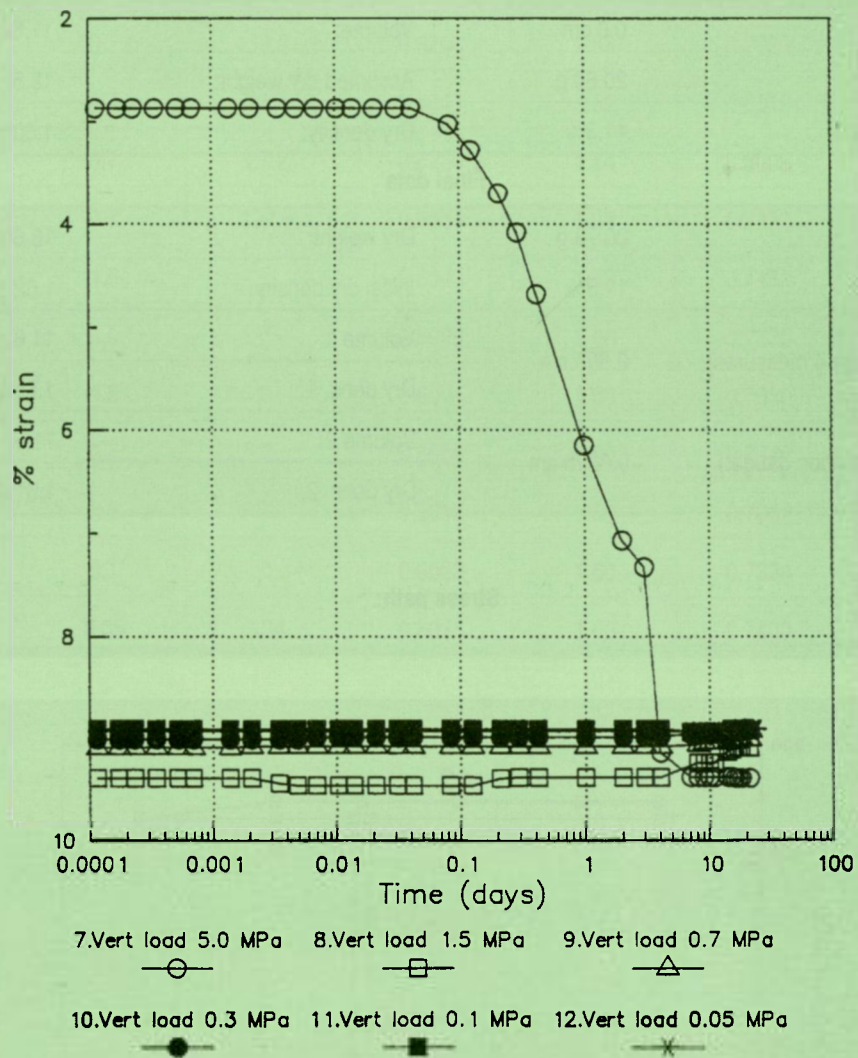


5.Suction 14 MPa 6.Suction 29 MPa 7.Suction 137 MPa

**Increasing suction pressure
at constant vertical load 5 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS3_2

Initial dry density 1.6 g/cm^3 , initial w 11.0%



Decreasing vertical load
at constant suction pressure 127 MPa

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS4_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	18-1-94	End:	

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

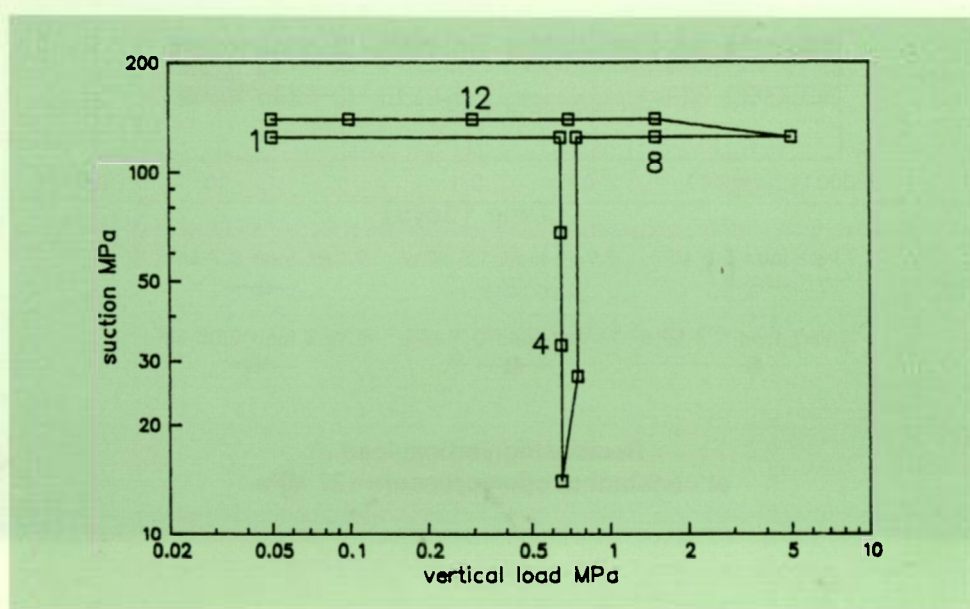
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.60 g	Assumed dry weight:	18.51 g
Water content:	11.3%	Dry density:	1.60 g/cm ³

Final data

Weight:	20.73 g	Dry weight:	18.66 g
Water content:	11.3%	Initial dry density:	1.62 g/cm ³
Final h (average 4 measures):	0.603 cm	Volume 1:	11.60 cm ³
		Dry dens. 1:	1.61 g/cm ³
Final h (deformation gauge:)	0.6026 cm	Volume 2:	11.59 cm ³
		Dry dens. 2:	1.61 g/cm ³

Stress path:

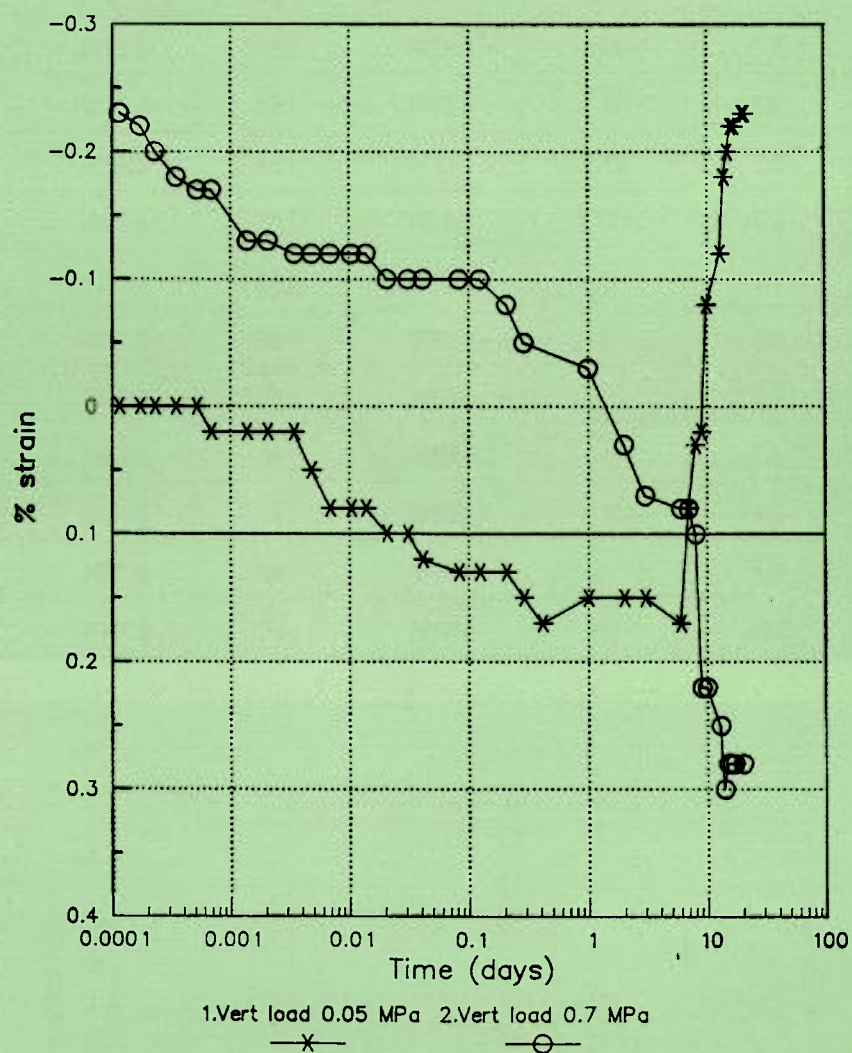


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS4_2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.7370	42.4
1	0.05	134	0.6014	1.60	0.7368	42.5
2	0.7	132.5	0.6017	1.60	0.7377	42.5
3	0.7	67.7	0.6070	1.58	0.7530	43.0
4	0.7	33.0	0.6208	1.55	0.7928	44.3
5	0.7	13.7	0.6341	1.52	0.8312	45.4
6	0.7	27.2	0.6234	1.54	0.8003	44.5
7	0.7	137.8	0.6054	1.59	0.7483	42.9
8	1.5	"	0.6043	1.59	0.7452	42.8
9	5.0	"	0.5999	1.60	0.7325	42.3
10	1.5	"	0.6001	1.60	0.7330	42.3
11	0.7	"	0.6006	1.60	0.7345	42.4
12	0.3	"	0.6012	1.60	0.7362	42.5
13	0.1	"	0.6023	1.60	0.7394	42.6
14	0.05	134	0.6026	1.60	0.7403	42.6

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_2

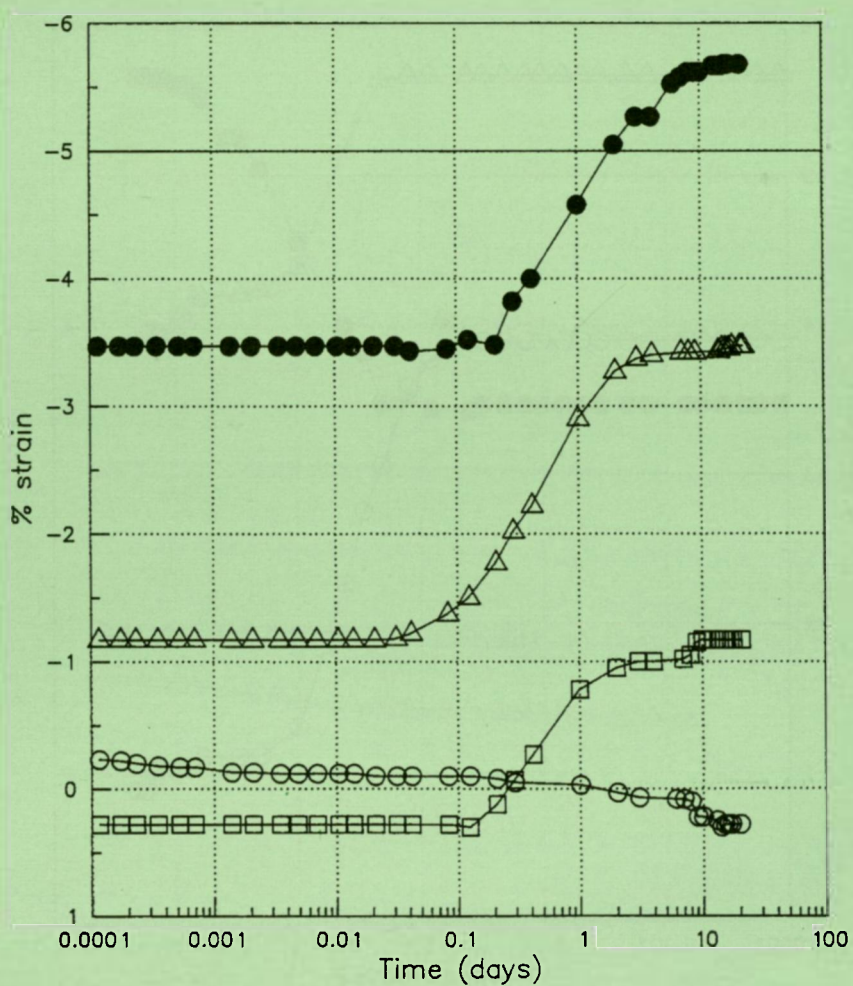
Initial dry density 1.6 g/cm^3 , initial w 11.2%



Increasing vertical load
at constant suction pressure 132 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_2

Initial dry density 1.6 g/cm^3 , initial w 11.2%



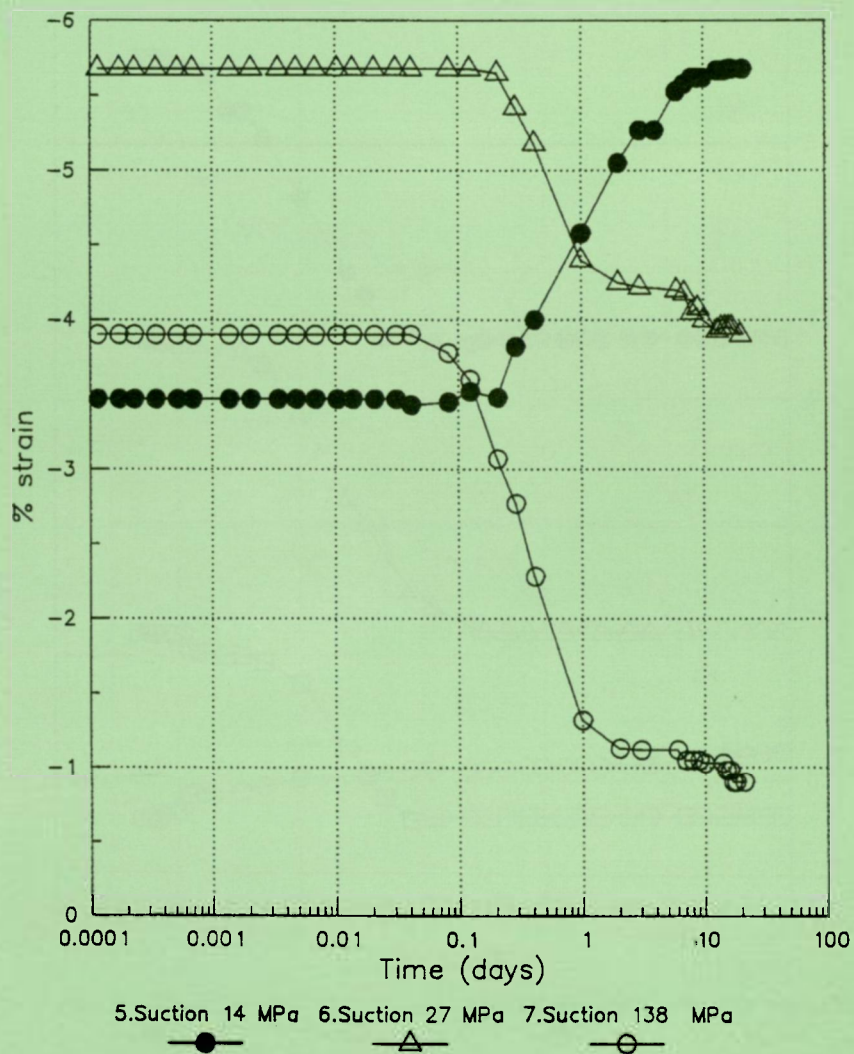
2.Suction 132 MPa 3.Suction 68 MPa 4.Suction 33 MPa 5.Suction 14 MPa

○ □ △ ●

**Decreasing suction pressure
at constant vertical load 0.7 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_2

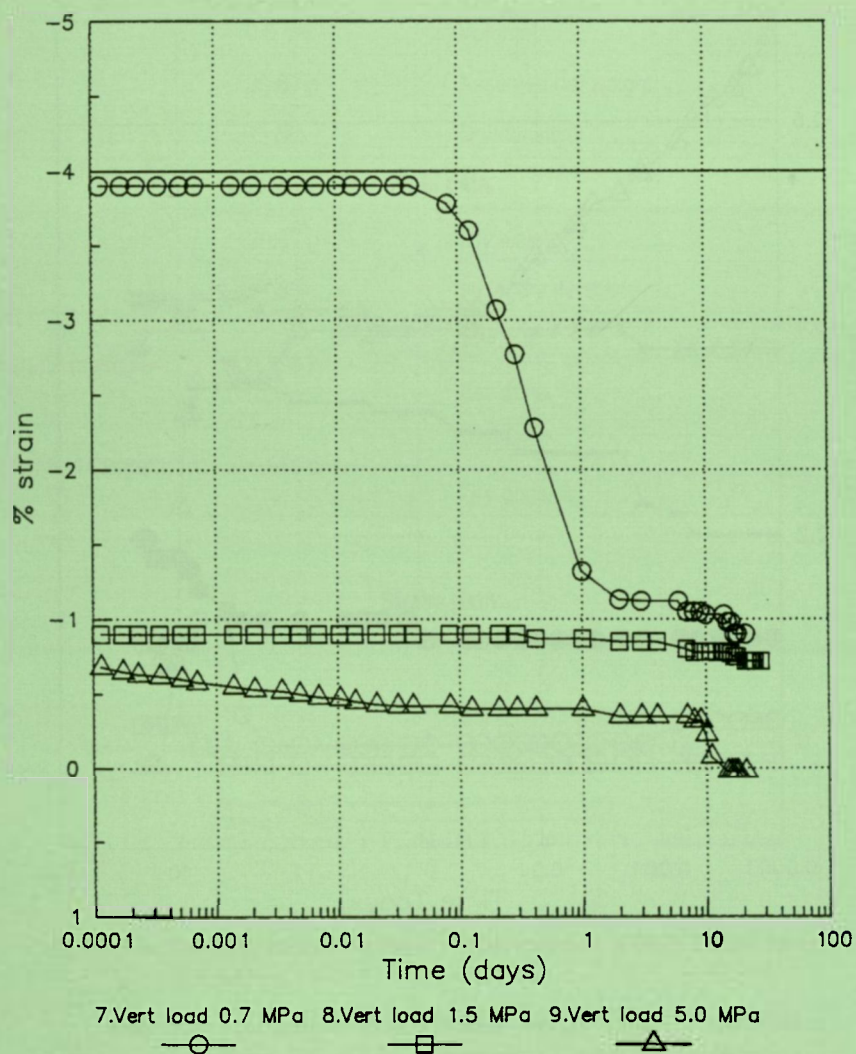
Initial dry density 1.6 g/cm³, initial w 11.2%



Increasing suction pressure
at constant vertical load 0.7 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_2

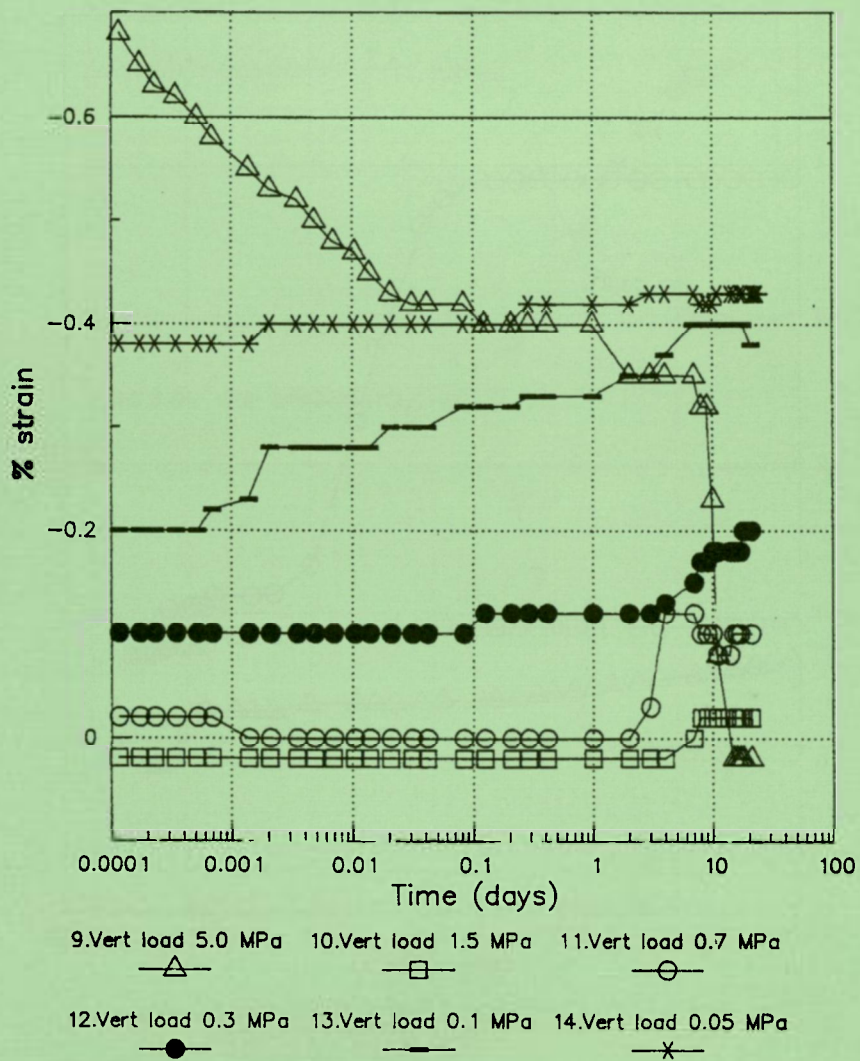
Initial dry density 1.6 g/cm^3 , initial w 11.2%



Increasing vertical load
at constant suction pressure 138 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS4_2

Initial dry density 1.6 g/cm^3 , initial w 11.2%



**Decreasing vertical load
at constant suction pressure 134 MPa**

SUCTION CONTROLLED OEDOMETRIC TESTS. SULFURIC ACID

Reference:	EDS5_2		
Material:	Montmorillonite	Specific weight:	2.78 g/cm ³
Start:	19-1-94	End:	3-11-94

Sample dimensions

Diameter:	4.95 cm	Surface:	19.24 cm ²
-----------	---------	----------	-----------------------

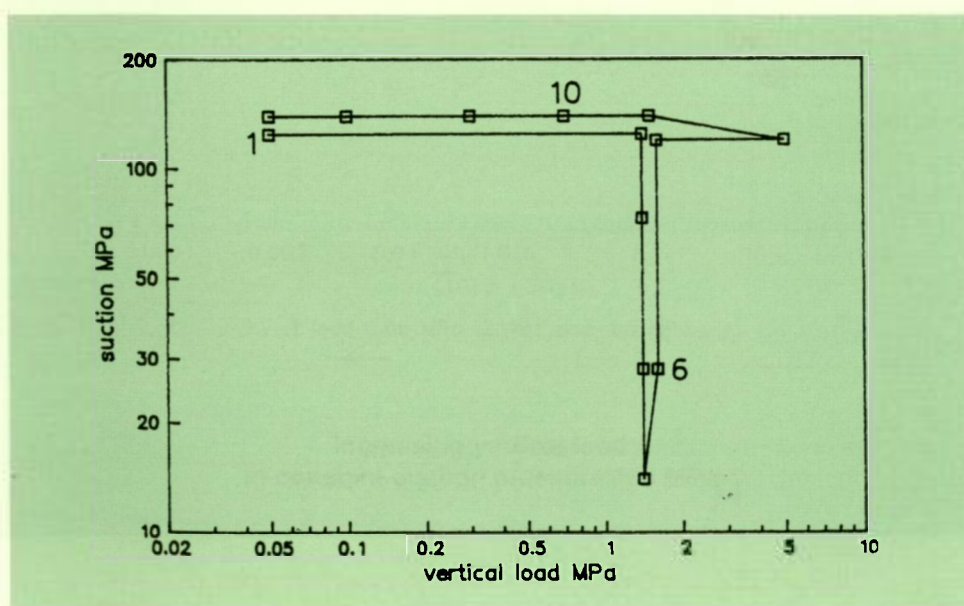
Initial data

Height h:	0.6 cm	Volume:	11.54 cm ³
Weight:	20.60 g	Assumed dry weight:	18.51 g
Water content:	11.3%	Dry density:	1.60 g/cm ³

Final data

Weight:	20.67 g	Dry weight:	18.49 g
Water content:	11.8%	Initial dry density:	1.60 g/cm ³
Final h (average 4 measures):	0.595 cm	Volume 1:	11.45 cm ³
		Dry dens. 1:	1.62 g/cm ³
Final h (deformation gauge:)	0.584 cm	Volume 2:	11.24 cm ³
		Dry dens. 2:	1.65 g/cm ³

Stress path:

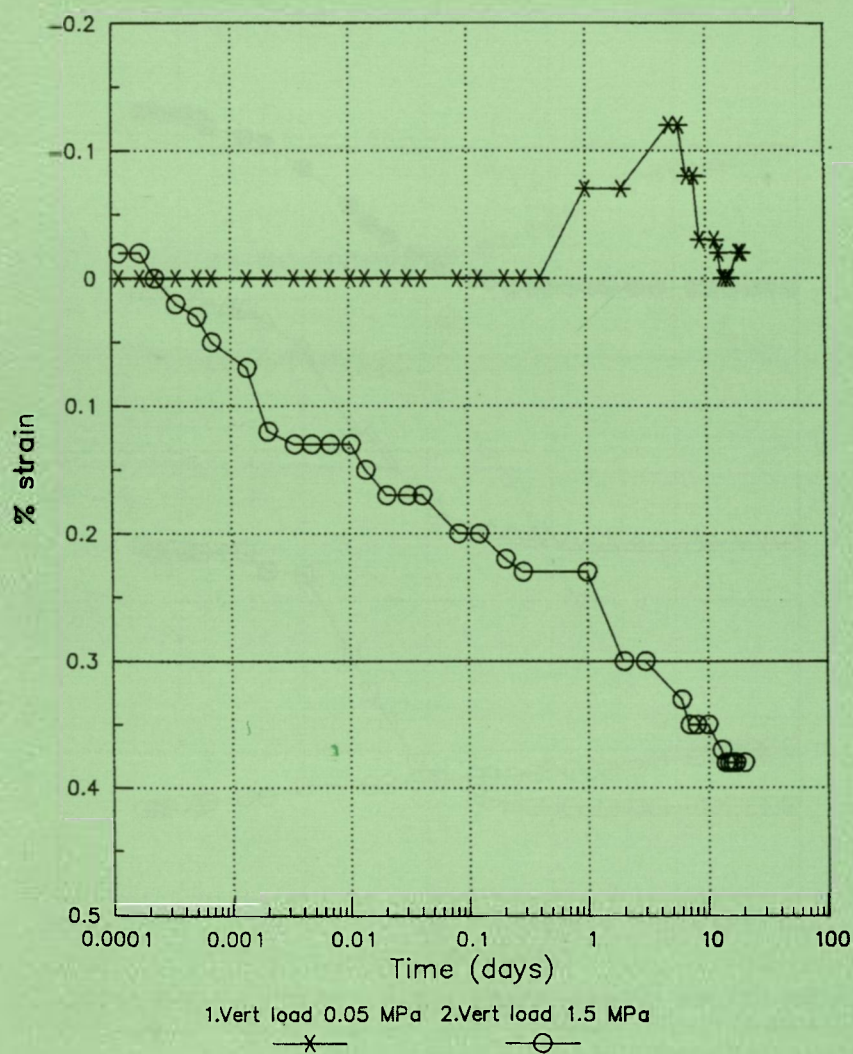


SUCTION CONTROLLED OEDOMETERS. SULFURIC ACID. EDS5_2

# Step	Vert. load MPa	Suction MPa	Final height cm	Dry dens. (g/cm ³)	Void ratio e	Porosity n
0	20.0	131.0	0.6000	1.60	0.7370	42.4
1	0.05	134	0.6001	1.60	0.7330	42.3
2	1.5	132.8	0.6023	1.60	0.7394	42.6
3	1.5	72.6	0.6082	1.58	0.7564	43.1
4	1.5	28.4	0.6184	1.56	0.7859	44.1
5	1.5	13.6	0.6254	1.54	0.8061	44.7
6	1.5	27.6	0.6112	1.57	0.7651	43.4
7	1.5	138.0	0.5843	1.65	0.6874	40.9
8	5.0	"	0.5799	1.66	0.6747	40.3
9	1.5	"	0.5807	1.66	0.6770	40.4
10	0.7	"	0.5814	1.65	0.6790	40.5
11	0.3	"	0.5822	1.65	0.6813	40.6
12	0.1	"	0.5837	1.65	0.6813	40.6
13	0.05	133.7	0.5840	1.65	0.6813	40.6

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_2

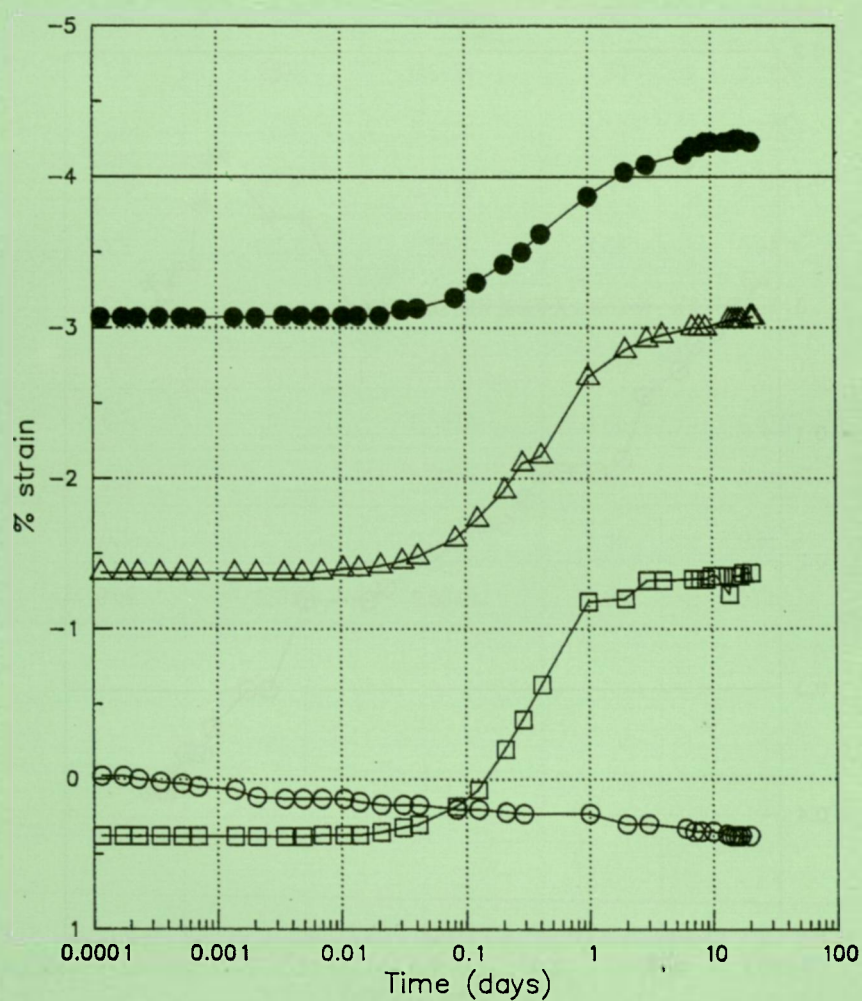
Initial dry density 1.6 g/cm^3 , initial w 11.2%



Increasing vertical load
at constant suction pressure 133 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_2

Initial dry density 1.6 g/cm³, initial w 11.2%



2.Suction 133 MPa 3.Suction 73 MPa 4.Suction 28 MPa 5.Suction 14 MPa

○

□

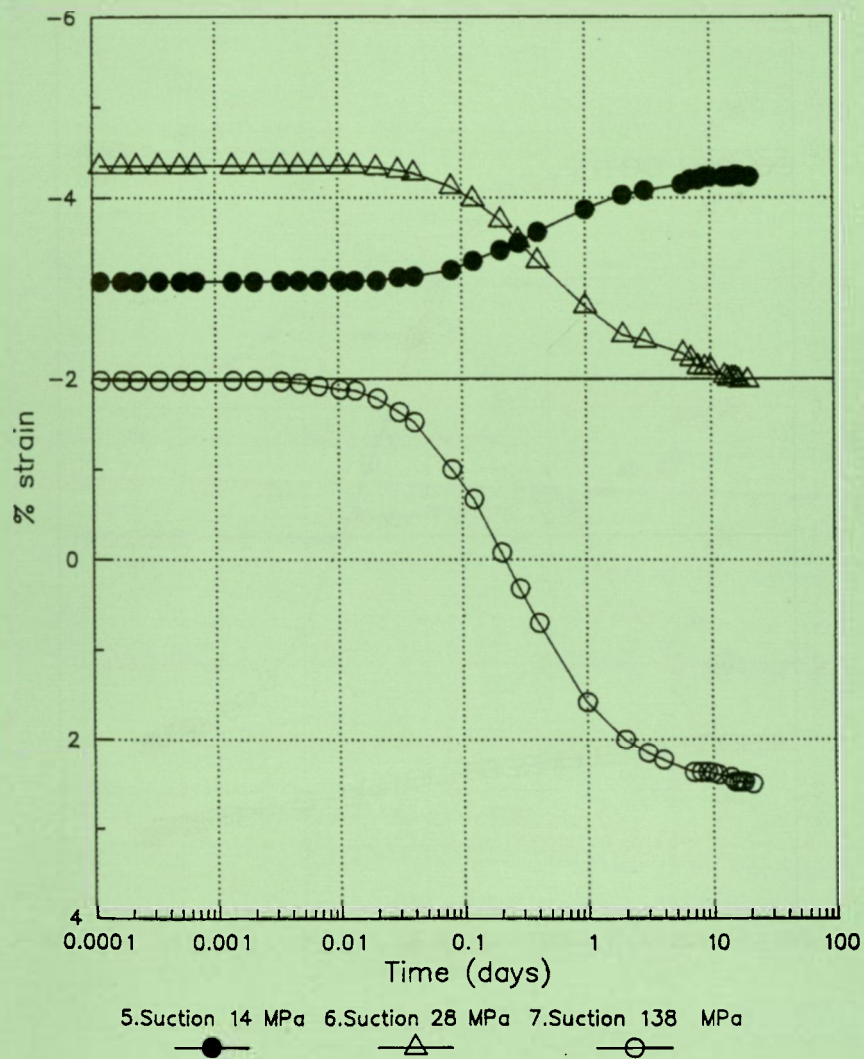
△

●

Decreasing suction pressure
at constant vertical load 1.5 MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_2

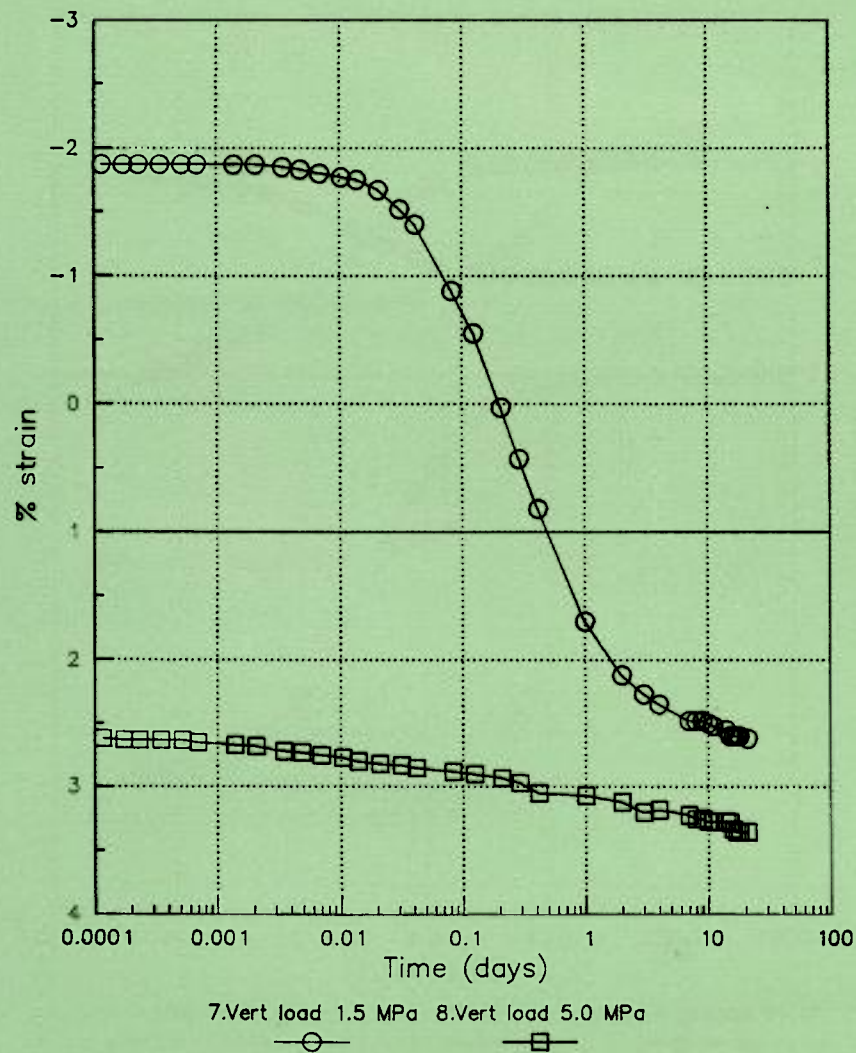
Initial dry density 1.6 g/cm^3 , initial w 11.2%



**Increasing suction pressure
 at constant vertical load 1.5 MPa**

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_2

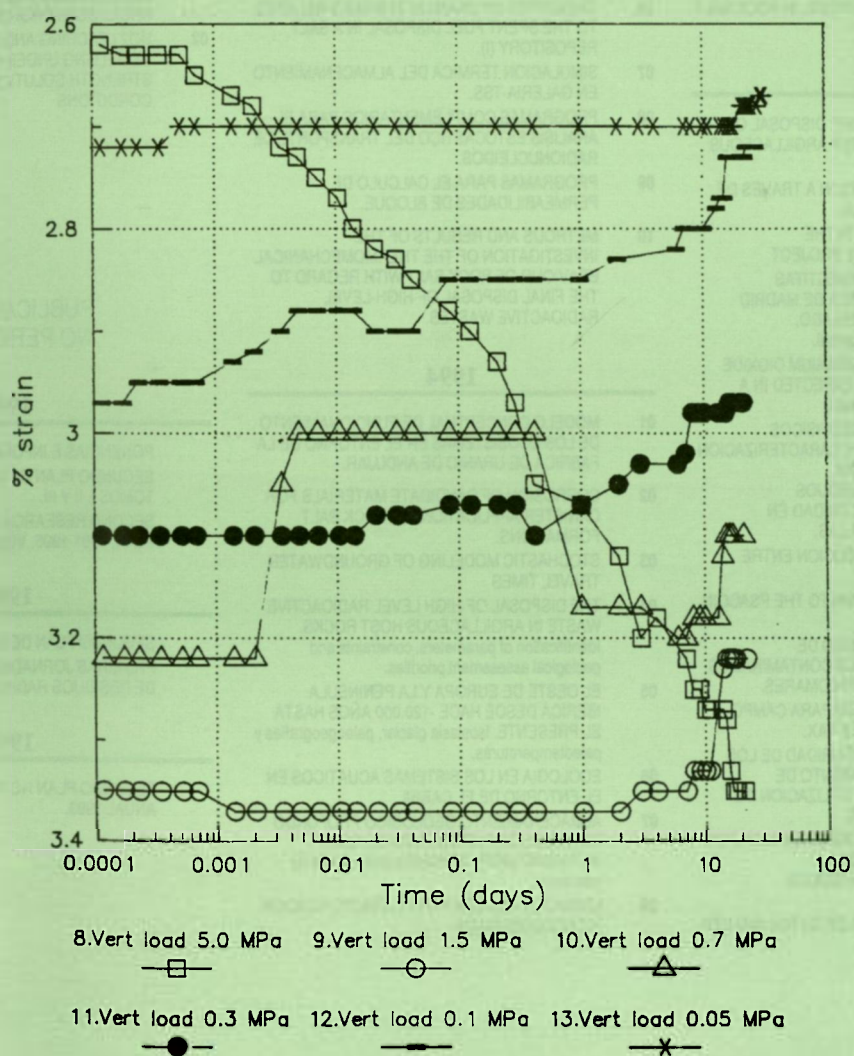
Initial dry density 1.6 g/cm³, initial w 11.2%



Increasing vertical load
at constant suction pressure 138? MPa

SUCTION CONTROLLED OEDOMETRIC TEST. SULFURIC
Consolidation curves. Montmorillonite EDS5_2

Initial dry density 1.6 g/cm^3 , initial w 11.2%



Decreasing vertical load
at constant suction pressure 134 MPa

PUBLICACIONES TECNICAS

1991

- 01 REVISION SOBRE LOS MODELOS NUMERICOS RELACIONADOS CON EL ALMACENAMIENTO DE RESIDUOS RADIOACTIVOS.
- 02 REVISION SOBRE LOS MODELOS NUMERICOS RELACIONADOS CON EL ALMACENAMIENTO DE RESIDUOS RADIOACTIVOS. ANEXO 1. Guía de códigos aplicables.
- 03 PRELIMINARY SOLUBILITY STUDIES OF URANIUM DIOXIDE UNDER THE CONDITIONS EXPECTED IN A SALINE REPOSITORY.
- 04 GEOESTADISTICA PARA EL ANALISIS DE RIESGOS. Una introducción a la Geostatística no paramétrica.
- 05 SITUACIONES SINOPTICAS Y CAMPOS DE VIENTOS ASOCIADOS EN "EL CABRIL".
- 06 PARAMETERS, METHODOLOGIES AND PRIORITIES OF SITE SELECTION FOR RADIOACTIVE WASTE DISPOSAL IN ROCK SALT FORMATIONS.

1992

- 01 STATE OF THE ART REPORT: DISPOSAL OF RADIOACTIVE WASTE IN DEEP ARGILLACEOUS FORMATIONS.
- 02 ESTUDIO DE LA INFILTRACION A TRAVES DE LA COBERTERA DE LA FUA.
- 03 SPANISH PARTICIPATION IN THE INTERNATIONAL INTRAVALE PROJECT.
- 04 CARACTERIZACION DE ESMECTITAS MAGNESICAS DE LA CUENCA DE MADRID COMO MATERIALES DE SELLADO. Ensayos de alteración hidrotermal.
- 05 SOLUBILITY STUDIES OF URANIUM DIOXIDE UNDER THE CONDITIONS EXPECTED IN A SALINE REPOSITORY. Phase II
- 06 REVISION DE METODOS GEOFISICOS APPLICABLES AL ESTUDIO Y CARACTERIZACION DE EMPLAZAMIENTOS PARA ALMACENAMIENTO DE RESIDUOS RADIOACTIVOS DE ALTA ACTIVIDAD EN GRANITOS, SALES Y ARCILLAS.
- 07 COEFICIENTES DE DISTRIBUCION ENTRE RADIONUCLEIDOS.
- 08 CONTRIBUTION BY CTN-UPM TO THE PSACOIN LEVEL-S EXERCISE.
- 09 DESARROLLO DE UN MODELO DE RESUSPENSION DE SUELOS CONTAMINADOS. APLICACION AL AREA DE PALOMARES.
- 10 ESTUDIO DEL CODIGO FFSM PARA CAMPO LEJANO. IMPLANTACION EN VAX.
- 11 LA EVALUACION DE LA SEGURIDAD DE LOS SISTEMAS DE ALMACENAMIENTO DE RESIDUOS RADIOACTIVOS. UTILIZACION DE METODOS PROBABILISTAS.
- 12 METODOLOGIA CANADIENSE DE EVALUACION DE LA SEGURIDAD DE LOS ALMACENAMIENTOS DE RESIDUOS RADIOACTIVOS.
- 13 DESCRIPCION DE LA BASE DE DATOS WALKER.

1993

- 01 INVESTIGACION DE BENTONITAS COMO MATERIALES DE SELLADO PARA ALMACENAMIENTO DE RESIDUOS RADIOACTIVOS DE ALTA ACTIVIDAD. ZONA DE CABO DE GATA, ALMERIA.
- 02 TEMPERATURA DISTRIBUTION IN A HYPOTHETICAL SPENT NUCLEAR FUEL REPOSITORY IN A SALT DOME.
- 03 ANALISIS DEL CONTENIDO EN AGUA EN FORMACIONES SALINAS. Su aplicación al almacenamiento de residuos radiactivos
- 04 SPANISH PARTICIPATION IN THE HAW PROJECT. Laboratory Investigations on Gamma Irradiation Effects in Rock Salt.
- 05 CARACTERIZACION Y VALIDACION INDUSTRIAL DE MATERIALES ARCILLOSOS COMO BARRERA DE INGENIERIA.
- 06 CHEMISTRY OF URANIUM IN BRINES RELATED TO THE SPENT FUEL DISPOSAL IN A SALT REPOSITORY (I).
- 07 SIMULACION TERMICA DEL ALMACENAMIENTO EN GALERIA-TSS.
- 08 PROGRAMAS COMPLEMENTARIOS PARA EL ANALISIS ESTOCASTICO DEL TRANSPORTE DE RADIONUCLEIDOS.
- 09 PROGRAMAS PARA EL CALCULO DE PERMEABILIDADES DE BLOQUE.
- 10 METHODS AND RESULTS OF THE INVESTIGATION OF THE THERMOMECHANICAL BEHAVIOUR OF ROCK SALT WITH REGARD TO THE FINAL DISPOSAL OF HIGH-LEVEL RADIOACTIVE WASTES.

1994

- 01 MODELO CONCEPTUAL DE FUNCIONAMIENTO DE LOS ECOSISTEMAS EN EL ENTORNO DE LA FABRICA DE URANIO DE ANDUJAR.
- 02 CORROSION OF CANDIDATE MATERIALS FOR CANISTER APPLICATIONS IN ROCK SALT FORMATIONS.
- 03 STOCHASTIC MODELING OF GROUNDWATER TRAVEL TIMES
- 04 THE DISPOSAL OF HIGH LEVEL RADIOACTIVE WASTE IN ARGILLACEOUS HOST ROCKS. Identification of parameters, constraints and geological assessment priorities.
- 05 EL OESTE DE EUROPA Y LA PENINSULA IBERICA DESDE HACE 120.000 AÑOS HASTA EL PRESENTE. Isostasia glacial, paleogeografías y paleotemperaturas.
- 06 ECOLOGIA EN LOS SISTEMAS ACUATICOS EN EL ENTORNO DE EL CABRIL.
- 07 ALMACENAMIENTO GEOLOGICO PROFUNDO DE RESIDUOS RADIOACTIVOS DE ALTA ACTIVIDAD (AGP). Conceptos preliminares de referencia.
- 08 UNIDADES MOVILES PARA CARACTERIZACION HIDROGEOQUIMICA

- 09 EXPERIENCIAS PRELIMINARES DE MIGRACION DE RADIONUCLEIDOS CON MATERIALES GRANITICOS. EL BERROCAL, ESPAÑA.
- 10 ESTUDIOS DE DESEQUILIBRIOS ISOTOPICOS DE SERIES RADIOACTIVAS NATURALES EN UN AMBIENTE GRANITICO: PLUTON DE EL BERROCAL (TOLEDO).
- 11 RELACION ENTRE PARAMETROS GEOFISICOS E HIDROGEOLOGICOS. Una revisión de literatura.
- 12 DISEÑO Y CONSTRUCCION DE LA COBERTURA MULTICAPA DEL DIQUE DE ESTERILES DE LA FABRICA DE URANIO DE ANDUJAR.

1995

- 01 DETERMINACION DEL MODULO DE ELASTICIDAD DE FORMACIONES ARCILLOSAS PROFUNDAS.
- 02 UO2 LEACHING AND RADIONUCLIDE RELEASE MODELLING UNDER HIGH AND LOW IONIC STRENGTH SOLUTION AND OXIDATION CONDITIONS

PUBLICACIONES NO PERIODICAS

1992

PONENCIAS E INFORMES, 1988-1991.
SEGUNDO PLAN DE I+D, 1991-1995.
TOMOS I, II Y III.
SECOND RESEARCH AND DEVELOPMENT PLAN, 1991-1995. VOLUME I.

1993

SEGUNDO PLAN DE I+D. INFORME ANUAL 1992.
PRIMERAS JORNADAS DE I+D EN LA GESTION DE RESIDUOS RADIOACTIVOS. TOMOS I Y II.

1994

SEGUNDO PLAN I+D 1991-1995. INFORME ANUAL 1993.

Edita:

enresa

empresa nacional de residuos radiactivos, s.a.

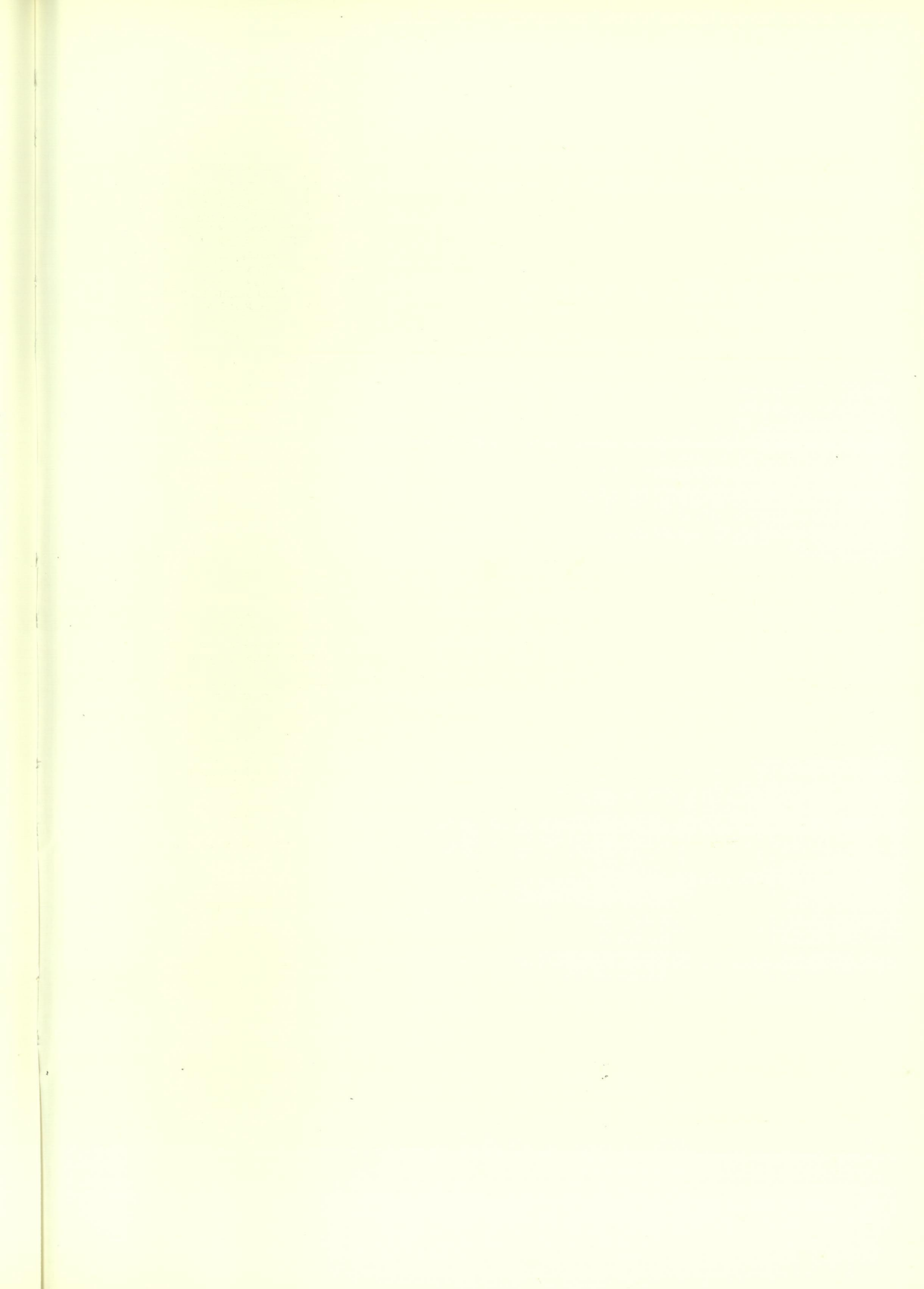
Diseño y coordinación editorial: TransEdit

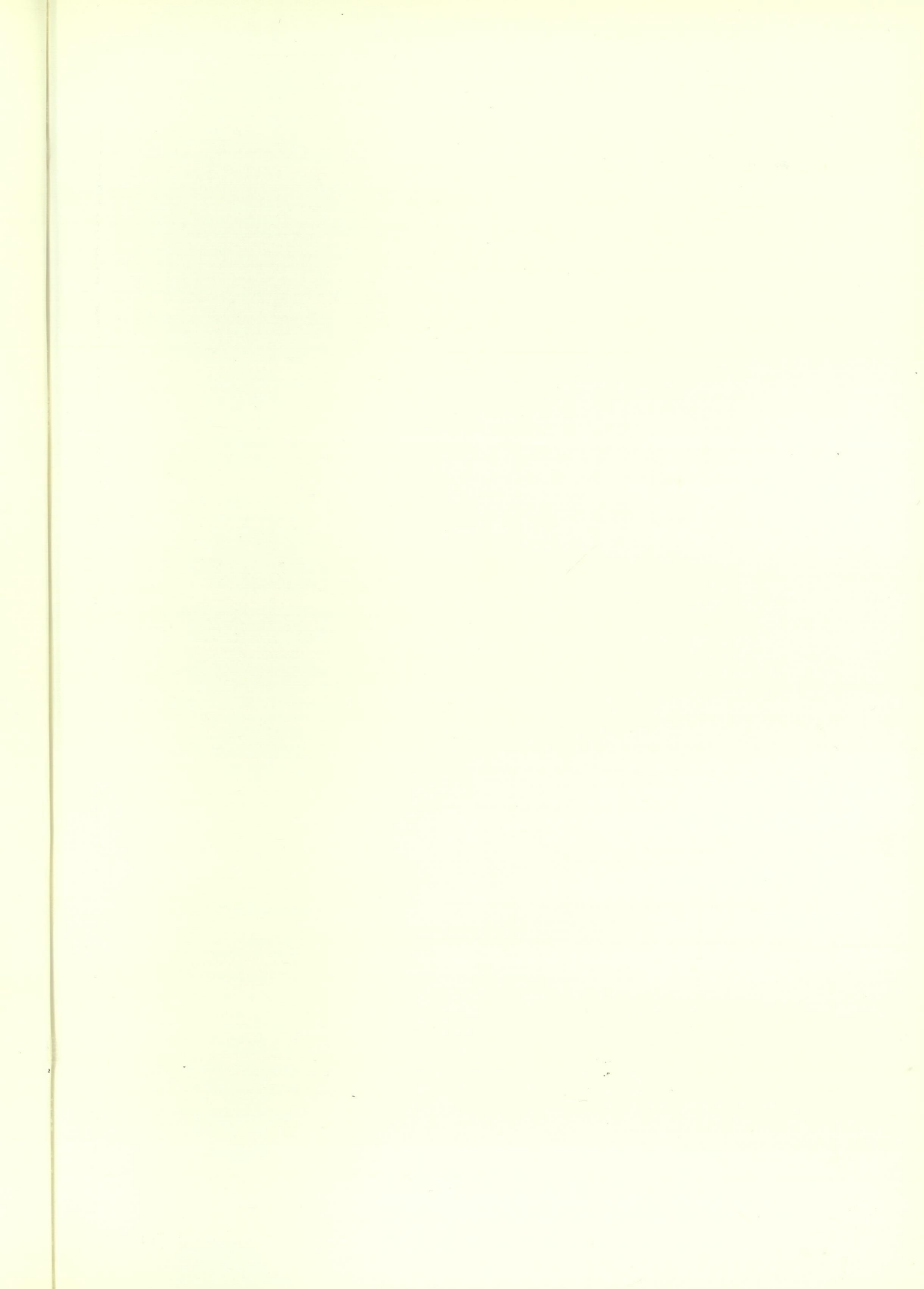
Impresión: Comercial Gráficas KELI

ISSN: 1134-380X

D.L.: M-

Mayo de 1995





**empresa nacional
de residuos radiactivos, s.a.**

Emilio Vargas, 7
28043 Madrid
Tels.: 519 52 55/519 52 63
Fax: 519 52 68

MARZO 95