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RESEARCH ON SOIL CONSOLIDATION USING CONSOLIDATION CELL UNDER CONSTANT RATE OF STRAIN

BY

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Abstract. Estimation for different building settlements on soils made of clay may require the development of special laboratory tests using different techniques to attempt standard oedometer test. It is often necessary to determine the coefficient of the consolidation in the horizontal direction to the vertical direction normal in conventional tests. Determination of preconsolidation pressure accurately based on data from classical test certain types of clay is often difficult. As a result, a number of special equipment and test procedures have been proposed to achieve these types of tests since from the 60's.

In response to this need have been conducted a series of tests using continues cell consolidation from the Department Of Transportation Infrastructure and Foundations.

Crawford (1959 and 1964) showed that he used at the tests of consolidation the constant rate of strain (CRS) to accelerate the testing and sample materials under strain rate, which approximates more deformation rates of soil, considered one of the pioneers in this field.

Key words: consolidation; specimen; rate of strain; settlements.

1. Introduction

Due to the many advantages, the constant rate of strain testing has been adopted in many countries, becoming a standard option for the determination of

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consolidation of clays. It was adopted by the Swedish Geotechnical Institute, the Norwegian Geotechnical Institute, The French Laboratory of Bridges and Highways and American Society for Testing and Materials (ASTM).

Due to the natural density of clayey soils, the way of consolidation is strongly influenced by the rate of their deformability. Also sedimentary clays such as soft clay, have anisotropic consolidation behavior with different properties in the vertical and horizontal consolidation. An understanding of the effect of strain rate on the behavior of the consolidation and the anisotropic consolidation is useful for developing geotechnical projects such as embankments, foundations in areas with clayey deposits.

Test under constant rate of strain was first presented by Hamilton and Crawford (1959) as a quick way of determining preconsolidation pressure $p_c^{'}$. This parameter was first defined by Casagrande in 1930 that linked a curve slope change e-log (*p*). Also appearing disadvantages associated with the use of e-log curve (*p*) resulting after oedometer test.

2. Laboratory Studies on Soil Consolidation

Generally, the experimental program is to investigate different types of soil consolidation, particularly in the watershed Bahlueț clays (sites I1 and I2).

This paper presents the strain rate effect on consolidation behavior of Bahlueț clay based on the vertical drainage CRS test results.

2.1. Consolidation Cell Under Constant Rate of Strain

This equipment is used to attempt to achieve a constant rate of strain by using a mechanical press capable of carrying out the test with a very low speed on the ground sample. In this way, axial loading is applied steadily increasing water pressure in the pores that are generated at the bottom of the soil sample. At the top there is mounted a drainage tube to allow the sample of soil to consolidate by the discharge of water from the sample.

During the test, the vertical movement and the pore water pressure are continuously monitored, as in the case of triaxial testing, the consolidated undrained (CU).

This test method covers the determination of the intensity and the rate of consolidation of the earth when it is prevented from deforming laterally and drained axially controlling axial loading.

Perform ongoing consolidation cell 26-WF0360 and other equipments, including triaxial frame, pressure system, data acquisition and processing system and other accessories (Fig. 1). Within the cell are two chambers separated by a membrane independent of special rubber, in such a way that they can be applied to two different pore water pressures:

a) outside the chamber for the pressure in the cell;

b) in the chamber where the sample is and where backpressure can be applied for saturation and accurate measurement of pore pressure.

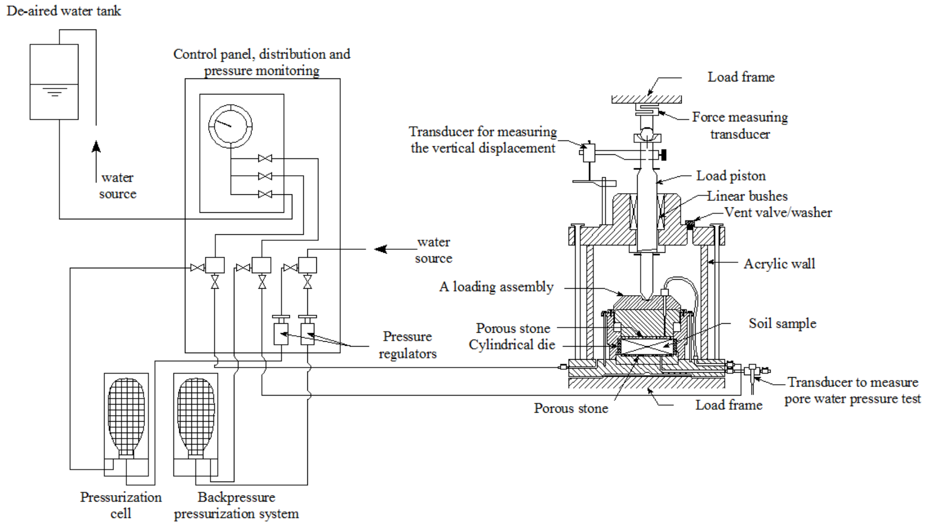

Fig. 1 – Schematic diagram of a consolidation cell under constant rate of strain using triaxial system.

Water pressure in the pores of the sample is measured with a pressure transducer. Drainage is connected to the top of the sample in order to allow the consolidation process.

2.2. Sampling and Preparation of Samples

Undisturbed soil samples (sample tubes) were obtained from different sites (I1 and I2) by taking them with specialized installation from the two locations indicated above.

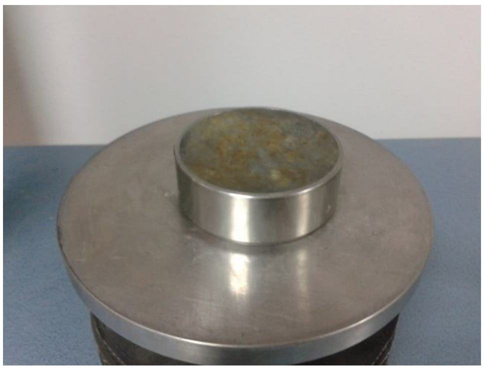

Fig. 2 – Soil sample resulting from sampling.

After sample tubes were transported to the laboratory, soil samples were taken from them, as the experimental tests achievement, and wrapped in plastic sheet to prevent moisture loss from the natural earth.

2.3. Equipment and Test Method

Preparation of test under constant rate of strain is shown in below figure. The device consists of a controlled axial movement and a back-pressure applied.

The soil sample extracted has a diameter of 63.5 mm and a height of 25.4 mm. To increase the degree of saturation of the sample, the sample is applied backpressure of 200 kPa during the test. Tests under constant rate of strain (CRS) were performed in accordance with ASTM D4186-06 (American Society for Testing and Materials), recommended in the manual instructions accompanying the cell consolidation under constant rate of strain. The tests were performed at a fixed rate of deformation of 0.1, 0.01, 0.02, 0.2 and 0.05 mm/min charging phase and the discharging phase a rate determined adjusted between 1/2 and 1/5 of the initial speed.

Fig. 3 – Triaxial loading framework.

2.4. Test Steps

Main stages of the test are summarized below:

a) Connection and filling up the system with de-aired water.

b) Saturation of the drainage lines and pore pressure de-airing block.

It is recommended to follow this procedure before placing the sample in the cell.

c) Assemble the specimen.

d) Procedures for the saturation stage.

e) Procedures for the consolidation stage.

For testing under constant rate of strain with vertical drainage, data processing will be done as follows (from the instruction manual cell, that respects reference standards ASTM D4186):

$$\sigma_v = \frac{P}{A} \cdot 10 , \tag{1}$$

$$\sigma_v^{'} = \left[\sigma_v^3 - 2\sigma_v^2 (U_B - U_0) + \sigma_v (U_B - U_0)^2 \right]^{1/3} , \tag{2}$$

where: σ_v is the total vertical stress, [kPa], $\sigma_v^{'}$ – effective vertical stress, [kPa], U_B – excess pore pressure at the bottom of the specimen, [kPa] and U_0 – initial pore pressure at the bottom of the specimen, [kPa].

The value of c_v (coefficient of consolidation) can be calculated as:

$$C_v = \frac{(\sigma_v)_2 - (\sigma_v)_1}{\frac{(U_B)_2 + (U_B)_1}{2} - U_0} \cdot \frac{\left(\frac{H_0}{10} - \frac{\delta H_2 + \delta H_1}{20} \right)^2}{2 \cdot 60 \cdot (t_2 - t_1)} , \tag{3}$$

when the excess of pore pressure is less than 5% of the total stress, expressed in cm^2/s.

Or, the value of c_v can be calculated as:

$$C_v = \frac{\left[\frac{H_0}{10} - \frac{\delta H_2 + \delta H_1}{20} \right]^2 \log \left[\frac{(\sigma_v)_2}{(\sigma_v)_1} \right]}{2 \times 60 (t_2 - t_1) \log \left[1 - \frac{(U_B)_2 + (U_B)_1}{(\sigma_v)_2 + (\sigma_v)_1} \right]} , \tag{4}$$

when the excess of pore pressure is between 5 and 20% of the total stress, expressed in cm^2/s.

The coefficient of permeability can be calculated as:

$$k = C_v 9.81 \gamma_w \frac{1}{M} 10^{-4} , \tag{5}$$

where: k – coefficient of permeability, [cm/s], M – constrained modulus, [kPa], γ_w – density of water, [kN/m^3].

Were conducted 15 trial test under constant rate of strain in accordance with the conditions on the ground, with vertical drainage. The loading and the drainage conditions for the test under a constant rate of deformation are shown in Fig. 4. Deformation rates used for testing under constant rate of strain were

0.1, 0.01, 0.02, 0.2 and 0.05 mm/min. Total tests carried out are shown in Table 1.

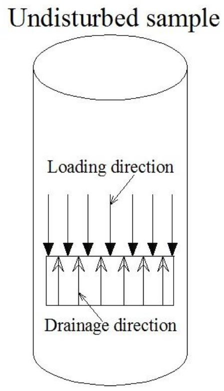

Fig. 4 – Loading and drainage conditions for testing under constant rate of strain.

Table 1
Centralization Attempts

Location	Borehole	Type of test	Strain rate mm/min
I1	F2, 8.00 m	CU	0.01, 0.02, 0.2
	F3, 7.00 m	CU	0.01, 0.02, 0.2
	F4, 4.00 m	CU	0.02, 0.05
	F4, 16.50 m	CU	0.01
I2	F2, 1.00 m	CU	0.01
	F4, 9.50 m	CU	0.1, 0.02

3. The Test Results under Constant Rate of Strain with Vertical Drainage

3.1. Effect of Strain Rate on the Consolidation Effort

In general, the stress-strain curves pass in a manner parallel to the right with increasing strain rate, similar to results reported in the literature (Graham *et al*., 1983; Leroueil *et al*., 1985; Vaid *et al*. 1979) .

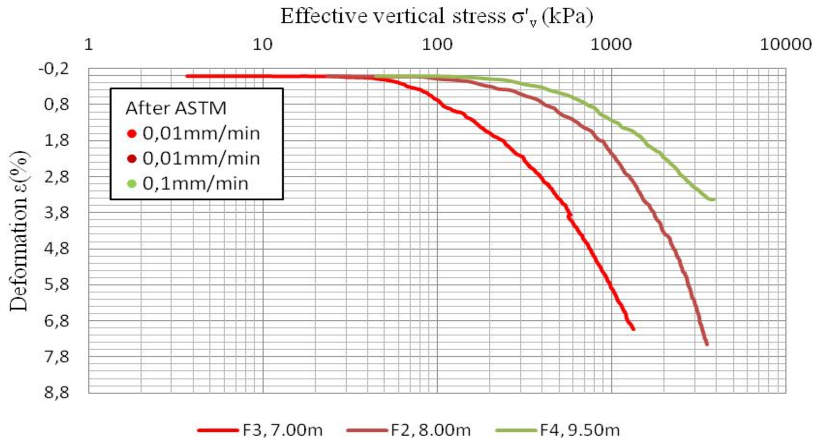

Fig. 5 – Stress-strain–strain rate relation (F3, F2, F4).

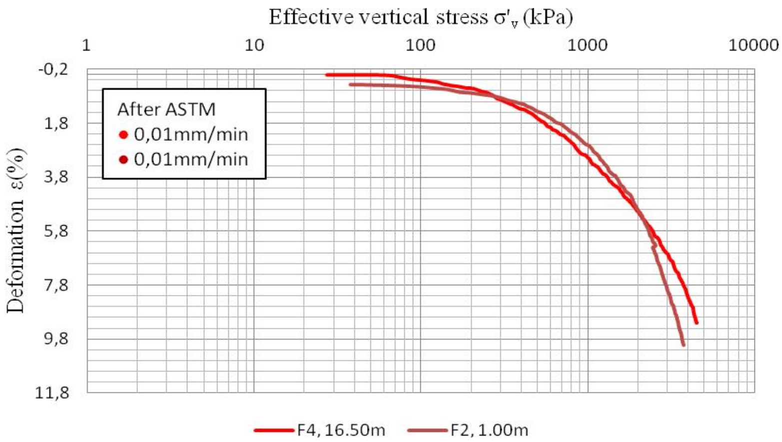

Fig. 6 – Stress-strain–strain rate relation (F4, F2).

3.2. The Test Results under Constant Rate of Strain In Steps

One of the reasons given varied results is that different soil samples had to be used at different strain rates of deformation. Samples extruded from the thin-wall tubes are treated as having the same properties and behavior, but due to spatial variation of the soil from the deposit, they may vary. To avoid these problems, stepwise constant rate of strain tests were conducted, which used the same samples subjected to two different strain rates.

From the following figure it is observed that when the strain rate was increased or decreased abruptly, the effective vertical stress showed an obvious increase or decrease.

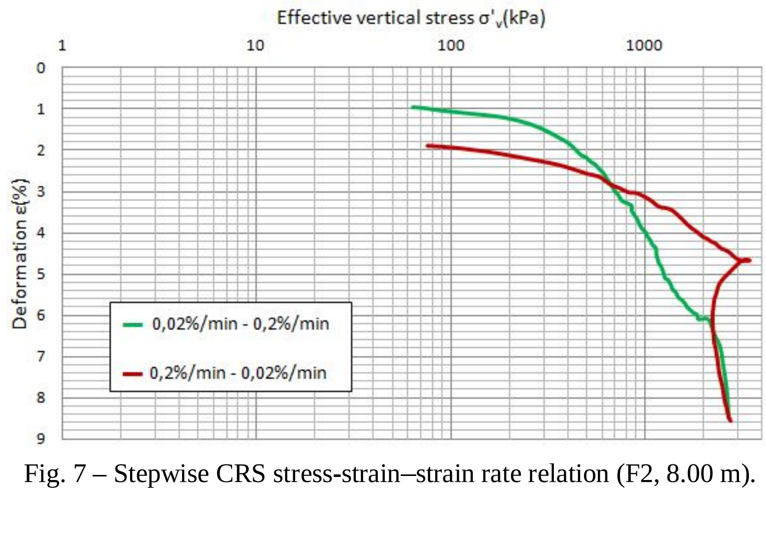

Fig. 7 – Stepwise CRS stress-strain–strain rate relation (F2, 8.00 m).

3.3. The Curve of the Pore Water Pressure During Consolidation

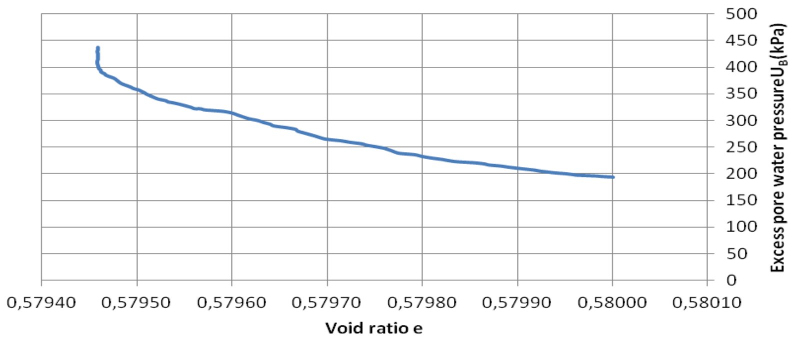

Fig. 8 – Variation of excess pore water pressure during consolidation (F4, 9.50 m).

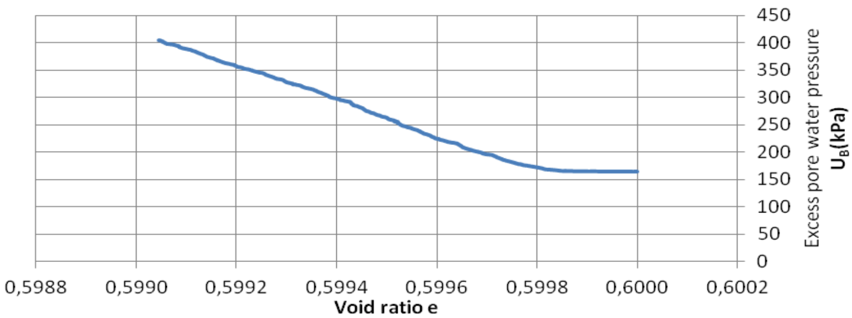

Fig. 9 – Variation of excess pore water pressure during consolidation (F3, 7.00 m).

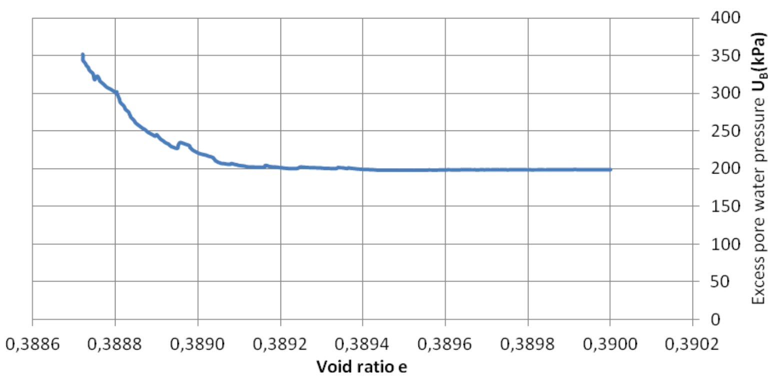

Fig. 10 – Variation of excess pore water pressure during consolidation (F4, 16.50 m).

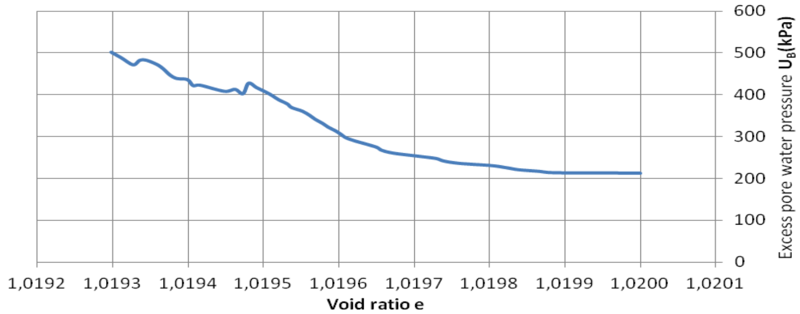

Fig. 11 – Variation of excess pore water pressure during consolidation (F4, 4.00 m).

It is observed that as the effective stress increases and void ratio decreases, excess pore water pressure in the underlying sample increases.

3.4. Comparison of Consolidation Coefficient Values Obtained from Tests Under Constant Rate of Strain and Incremental Loading (Oedmeter Test)

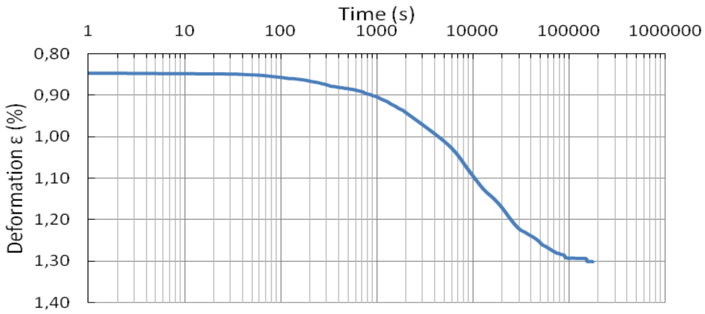

Fig. 12 – Compression-consolidation curve in oedometer (F2, 8.00 m).

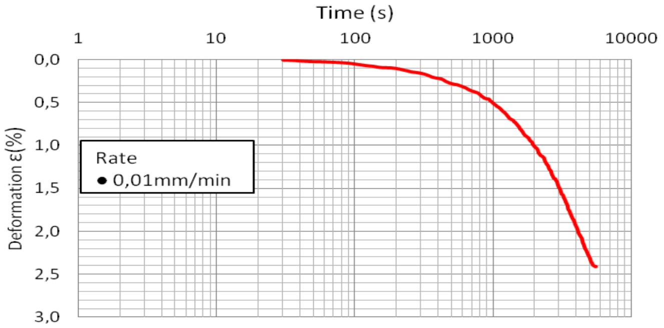

Fig. 13 – Compression-consolidation curve under constant rate of strain (F2, 8.00 m).

It is observed that compression-consolidation curve graph obtained from incremental loading for step load test of 500 kPa get to surprise addition to primary consolidation and secondary consolidation of soil sample. While building the graph obtained by testing under constant rate of strain, due to the appropriate choice of the strain rate (0.01 mm/min for this condition), the secondary consolidation is reduced in this case, the test can be completed very quickly, as opposed to trying oedometer test which may take several weeks.

4. Conclusions

Based on the results of analyzes and tests presented in this paper, the following conclusions are drawn:

1. In general, the stress-strain curves cross in a manner parallel to the right with increasing deformation rate, which indicates that an isotropic model is applicable for the present study clay.

2. It is observed that as the void ratio decreases according to the increase of the effective stress, excessive water pressure in the pores of the base of the sample increases.

3. For a given effective vertical stress, coefficient of consolidation increases with increasing strain rate resulting primarily from increased in hydraulic conductivity.

In this paper we wanted only to present the cell consolidation under constant rate of strain, working principles and calculations, and some of the results obtained. In a future article we intend to present some concrete results obtained from the use of consolidation cell under constant rate of strain.

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CERCETĂRI PRIVIND CONSOLIDAREA PĂMÂNTURILOR UTILIZÂND CELULA DE CONSOLIDARE SUB RATĂ CONSTANTĂ DE DEFORMABILITATE

(Rezumat)

Estimarea tasărilor pentru diferite construcții realizate pe pământuri argiloase poate necesita realizarea unor încercări speciale de laborator ce folosesc tehnici diferite față de încercarea edometrică standard. De multe ori este necesar a se determina coeficientul de consolidare în direcție orizontală față de direcția verticală, normală, în testele convenționale. Determinarea cu acuratețe a presiunii de preconsolidare pe baza datelor obținute în urma încercărilor clasice pe anumite tipuri de argilă este de multe ori dificilă. Ca rezultat, o serie de echipamente speciale şi proceduri de încercare au fost propuse pentru realizarea acestor tipuri de încercări încă din anii ’60.

Ca răspuns la această nevoie s-au realizat o serie de încercări de consolidare utilizând celula de consolidare sub rată constantă de deformabilitate din cadrul departamentului de Căi de Comunicații şi Fundații.

Crawford (1959 şi 1964) a prezentat că a folosit la încercările de consolidare, viteza constantă de deformare (VCD) pentru accelerarea procesului de testare şi pentru a încerca materialele sub viteze de deformare, care aproximează mai mult vitezele de deformare din teren, considerat ca fiind unul dintre pionierii din acest domeniu.