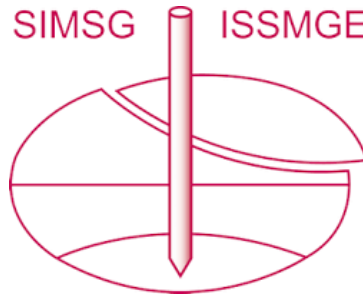


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Experimental tests regarding the estimation of soil preconsolidation pressure

Tests expérimentaux sur l'estimation de la pression de préconsolidation des sols

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ABSTRACT: Given the complexity of soil as a “material”, respectively its behavior influenced by a multitude of factors and the limitations of the oedometer test, the finding of a method to determine the value of the preconsolidation pressure has been a challenge for many prominent specialists in the field who had sought over time to find a general method to determine its value. Thus, it becomes impetuously necessary, that in research, to continuously verify the methods used to determine the value of the preconsolidation pressure. This article presents the findings and results obtained from a comparative analysis aimed at evaluating 11-methods and procedures, from the literature, used to determine the value of the preconsolidation pressure. In the experimental program, soil samples made of kaolinitic clay with artificial structure, consolidated at 150 kPa, were tested in the oedometer. The experimental program consisted of tests performed on 3 sets of samples, loaded up to different maximum pressures, different ways of applying the load and 24 hours of load keeping per each load step. At the first and second set of tests load steps were applied according to the specifications from the norms and at the third set of tests loads from 25 to 25 kPa were applied. The variation of the sample size and the methodology of application of the load, indicated above, was adopted to identify, at the same time, the method/procedure that can be applied also in atypical situations of performing the oedometer test.

RÉSUMÉ : Compte tenu de la complexité de la terre en tant que «matériau», du comportement influencé par une multitude de facteurs et des limites du test édométrique, trouver une méthode pour déterminer la valeur de la pression de préconsolidation a été un défi pour de nombreuses personnalités de marque, qui l'ont cherché au fil du temps. Pour trouver une méthode générale pour le déterminer. Ainsi, il devient impératif, en recherche, de vérifier en permanence les méthodes utilisées pour déterminer la valeur de la pression de préconsolidation. Cet article présente les constatations et les résultats obtenus à partir d'une analyse comparative visant à évaluer onze méthodes et procédures de la littérature utilisées pour déterminer la pression de préconsolidation. Au cours du programme expérimental, des échantillons de sol en argile kaolinitique à structure artificielle, consolidés à 150 kPa, ont été testés dans l'édomètre. Le programme expérimental consistait en des tests effectués sur 3 séries d'échantillons, avec des échantillons de différentes tailles, chargés jusqu'à différentes pressions maximales, différentes manières d'appliquer la charge et pendant 24 heures pour maintenir chaque étape de chargement. Des étapes de charge ont été appliquées aux premier et deuxième ensembles d'échantillons comme spécifié dans les normes, et des charges de 25 à 25 kPa ont été appliquées au troisième ensemble d'échantillons. La variation de la taille de l'échantillon et de la méthodologie d'application de la charge, indiquée ci-dessus, a été adoptée pour identifier, en même temps, la méthode / procédure qui peut être appliquée dans des situations atypiques de réalisation du test édométrique.

KEYWORDS: preconsolidation pressure, experimental tests, soil compressibility, oedometer test

1 INTRODUCTION

Soils by their compositions are defined as three-phase dispersed system. The distribution and the proportion of the three phases in the soils depends on how their skeleton was formed. The arrangement of particles of different sizes in space has led to the formation of pores of different shapes and sizes, which contain captive in various proportions the liquid and gaseous phases.

Following the loading of the soil layer, the pore size is reduced, and the liquid and gas content captive in the pore migrates to other areas where the pressure is felt less (internally) or not at all (externally), in this way soil becoming gradually consolidated until the applied external pressure is equalized with those developed inside.

A saturated soil or a sample of it will have all the pores filled with water. Depending on the permeability of the soil structure (grainy, honeycomb, flakes/flocculated or mixed – in different proportions) the consolidation will be done in a rhythm from fast (cohesionless soils) to slow and very slow (cohesive soils). Thus, porosity has an important role in defining the physical-mechanical characteristics of soils (Duncan 1991, Stanciu & Lungu 2006, Ilaș 2017).

The maximum load to which a layer of soil has been subjected during its existence, respectively under which the consolidation

has been achieved over time, represents the preconsolidation pressure.

By assimilation with the steel the preconsolidation pressure can be seen as the effort at the limit of the soil yield strength. This aspect makes it particularly important to determine, and moreover to correct/exactly determine, the preconsolidation pressure for the calculation of the geotechnical design of the structures. This description is, of course, an extremely simplified way of rendering the behavior of soils under loadings.

The methodology of the oedometer test, respectively the well-known laboratory test, is based on the principles listed above with some limitations starting from the fact that the lateral deformation is completely obstructed and the disturbance of the samples cannot always be controlled or stopped (Stanciu & Lungu 2006).

The oedometer test is used to investigate the characteristics that characterize the deformation of the soils and to establish the preconsolidation pressure.

In the case of determining the preconsolidation pressure, multiple methods have been developed, most of which are applied on the compression-settlement or compression-porosity curve drawn based on the results obtained from the oedometer test on a soil sample undisturbed (Katarzyna & Alojzy 2010) or considered undisturbed (Stanciu & Lungu 2006, Ilaș 2017).

2 THE EXPERIMENTAL PROGRAM

The following grapho-analytical methods were used in the experimental program to determine the preconsolidation pressure (σ'_p): Casagrande Method, L.C.P.C. Method, Van Zelst Method, Rutledge, Hvorslev and Schmertmann Method, Burmister Method, Pacheco Silva Method, Tavenas Method, Şenol Method, Old Method, Log-Log or Jose Method, Butterfield or Sridharan Method (Adel et al 2015, Bartlett & Alcorn 2004, Bowles 1996, Mohammed 2008, Papke 2011, Paniagua et al 2016, Senol et al 2006, Senol & Saglamer 2002, Schultze & Muhus 1967, Sillion et al 1987, Vendel 2013, Vipulanandan 2009).

2.1 Sample manufacturing

The oedometer samples within the experimental program were made from bigger samples, see Figure 1, previously consolidated at a pressure of 150 kPa, in an original designed device called Consolidometer, which offers the possibility of performing three types of tests (disturbed plate load test with sampling, plate load test without disturbance, triaxial test without disturbance) after the consolidation of the sample at the required preconsolidation pressure.

For bigger samples with dimensions of $\varnothing = 165$ mm and $h \approx 195$ mm, after consolidation in the device called Consolidometer, oedometer samples of different sizes were made for Set I and II of tests, see Figure 2. From the Consolidometer samples for Set I and II samples were made 4 oedometer samples with $\varnothing = 7.0$ cm and $h = 2.0$ cm, 3 samples with $\varnothing = 4.0$ cm and $h = 1.0$ cm and one sample with $\varnothing = 4.0$ cm and $h = 2.0$ cm, see Figure 2.



Figure 1. Consolidometer samples for Set I and II of oedometer samples.



Figure 2. Preparation of oedometer samples related to Set I and II.

The oedometer samples of Set III were made from specimens extracted from the middle of the Consolidometer sample, according to the methodology from two disturbed plate load test with sampling specific to the Consolidometer, see Figure 3. From each specimen were made 3 oedometer samples with $\varnothing = 4.0$ cm and $h = 1.0$ cm and one oedometer sample with $\varnothing = 4.0$ cm and $h = 2.0$ cm, see Figure 4.



Figure 3. Specimens extracted from the two disturbed plate load tests with sampling, of the Consolidometer, intended for the preparation of the Set III of oedometer samples.



Figure 4 Oedometer samples (of Set III) made from one specimen extracted from one disturbed plate load test with sampling.

2.2 Procedure of loading the oedometer samples

In the first stage of the experimental program, consisting of Set I of oedometer tests, the test methodology consisted, according to STAS 8942/1, in the application of an initial step of 6.75 kPa with a holding time of 30 min, followed by the application of the following loading and unloading steps: 12.5 – 25 – 50 – 100 – 200 – 300 – 500 – 200 – 50 – 12.5 kPa with a holding time of 24h per step.

In the second stage of the experimental program, consisting of Set II of oedometer tests, the test methodology consisted, according to STAS 8942/1, in the application of an initial step of 6.75 kPa with a holding time of 30 min, followed by the application of the following loading and unloading steps: 12.5 – 25 – 50 – 100 – 200 – 300 – 500 – 750 – 1000 – 500 – 200 – 50 – 12.5 kPa with a holding time of 24 h per step.

In the third stage of the experimental program, consisting of Set III of oedometer tests, the test methodology consisted, according to the Consolidometer methodology, in applying an initial step of 6.75 kPa with a holding time of 30 min, followed by the application of the following loading and unloading steps: 12.5 – 25 – 50 – 75 – 100 – 125 – 150 – 175 – 200 – 225 – 250 – 275 – 300 – 325 – 350 – 375 – 400 – 425 – 375 – 325 – 275 – 225 – 175 – 125 – 75 – 25 – 12.5 kPa with a holding time of 24 h per step.

3 EXPERIMENTAL RESULTS

The experimental program consisted in the application of 11-grapho-analytical procedures for determining the

preconsolidation pressure on three sets of oedometer samples made from kaolinite clay previously consolidated at a pressure of 150 kPa in an original designed device called Consolidometer (Ilaş 2017).

The following aspects must be taken into account in the case of laboratory reconstituted samples, respectively the shape of the compression-settlement and compression-porosity curves is more flattened than in the case of samples with natural structure and low degree of disturbance (Bowles, 1996), and including under laboratory controlled conditions the avoidance of soil samples disturbance cannot be easily avoided (Adel et al., 2015). A high degree of disturbance of the soil samples influences the value of the pore index (e), the compression indices (C_c and C_r) and the preconsolidation pressure (σ'_p), (Adel et al., 2015).

In the present comparative analysis, the values close to the preconsolidation pressure of 150 kPa, were considered those between 130 ÷ 160 kPa. Based on this presumption, the following observations were extracted:

- in the Set I of samples, values were obtained in the range specified with Tavenas Method in 8 of 8 samples, with the Casagrande Method in 6 of 8 samples and with Burmister Method in 5 of 8 samples (in addition, other 2 samples have values close to the considered limits, at the same time this method seems to overestimate the value in the samples with standardized size), see Figure 5;
- in the Set II of samples, values were obtained in the interval specified with Casagrande Method in 4 of 8 samples, the Butterfield or Sridharan Method and the Log-log or Jose Method and the Van Zelst Method in 2 of 8 samples. With the application of two more loading stages, the determination of the value of the preconsolidation pressure become more difficult, see Figure 6. In this case the Tavenas Method greatly overestimated the value of the preconsolidation pressure;
- in the Set III of samples, values were obtained in the range specified with Casagrande Method and Tavenas Method in 8 of 8 samples, the Log-Log and Jose Method in 6 of 8 samples and Buterfield or Sridharan and Burmister Method in 4 of 8 samples, see Figure 7. By applying the loading steps from 25 to 25 kPa it was observed that several methods indicated values in the range of values considered close to the value of the preconsolidation pressure.

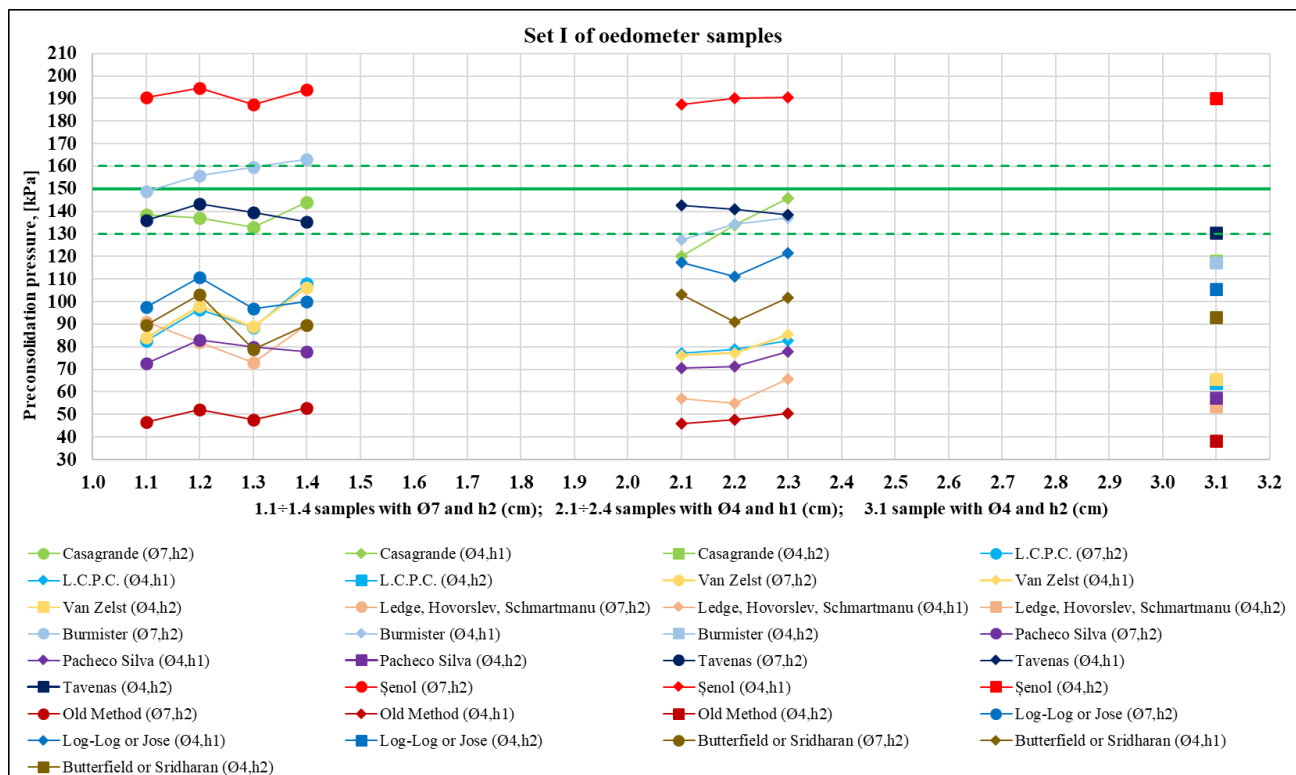


Figure 5. Graphical representation of the results of the tested Set I of oedometer samples.

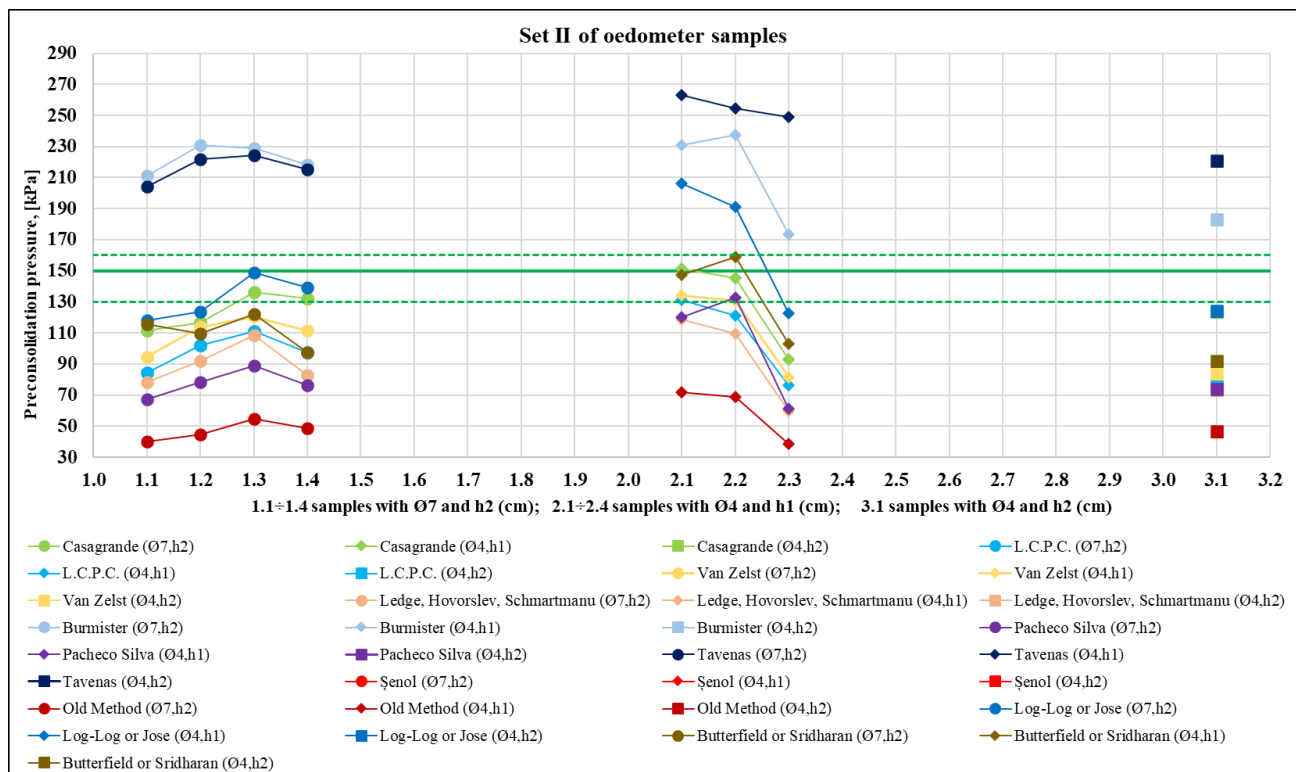


Figure 6. Graphical representation of the results of the tested Set II of oedometer samples.

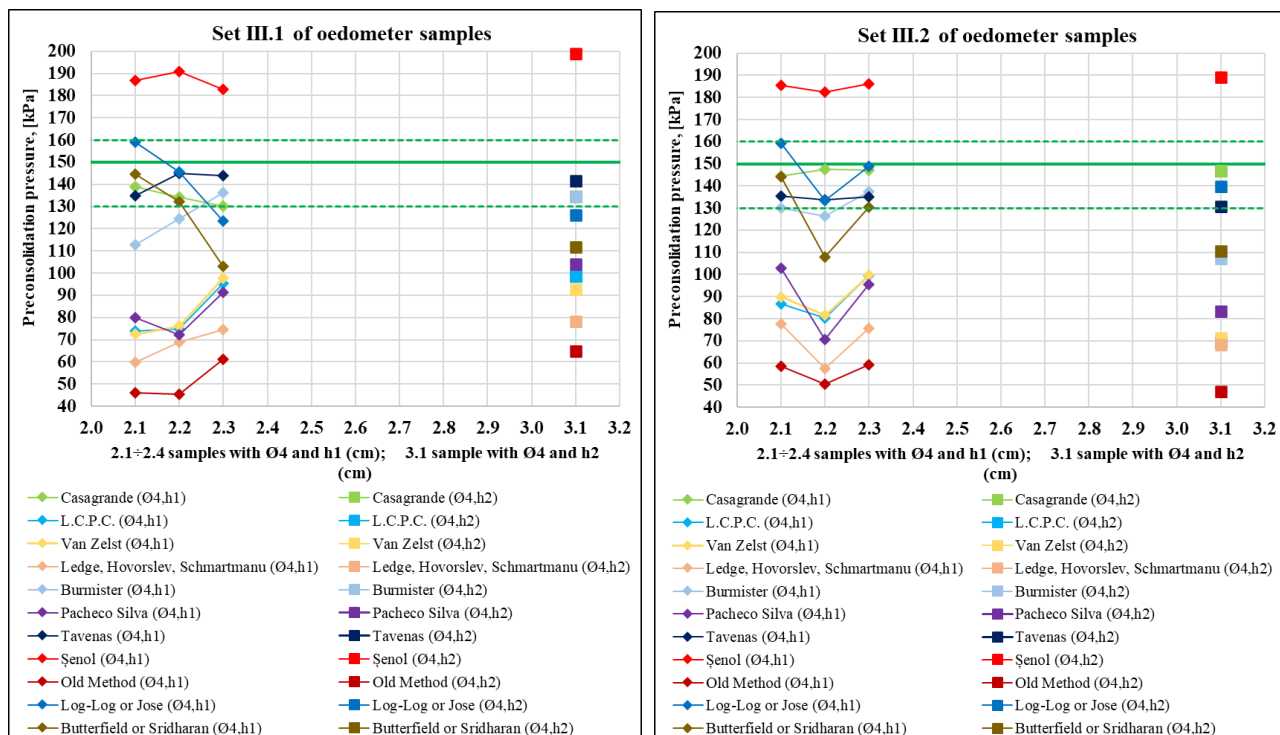


Figure 7. Graphical representation of the results of the tested Set III of oedometer samples.

4 CONCLUSIONS

Within the experimental program were applied 11 grapho-analytical methods, identified in the literature, to determine the preconsolidation pressure, respectively Casagrande (1936), L.C.P.C (1985), Van Zelst (1948), Ledge (1944) and Hvorslev (1949) and Schmertmann (1953), Burmister (1952), Pacheco Silva (1970), Tavenas (1979), Şenol (1997), Old (-), Log-Log or Jose (1989) and Butterfield (1979) or Sridharan (1991), on soil samples with reconstituted/artificial structure. The study was focused on oedometer tests on samples made of kaolinite clay paste brought to the upper limit of plasticity and consolidated at a preconsolidation pressure of 150 kPa.

Following the analysis of the value of the preconsolidation pressure determined by means of the 11 grapho-analytical methods, listed above, it was found that the most accurate method regardless of the sample size and the way of applying the load is Casagrande Method. The methodology for determining the point at which the curve is maximum according to (Silion, et al. 1987) is satisfactory in the case of a reconstituted sample. For oedometer samples loaded up to the loading step of 500 kPa, the Casagrande Method can be used concomitantly with the Tavenas Method for further verification given the accuracy observed in the analysis of the experimental results.

The correct determination of the preconsolidation pressure, based on the grapho-analytical methods, depends very much on the shape of the compression-settlement curves and implicitly compression-porosity, and in some cases on the loading steps application program (by the maximum loading stage and by the interval between the loading steps). By applying loading steps of low intensity, respectively from 25 to 25 kPa, the preconsolidation pressure can be determined with a greater precision using a bigger number of grapho-analytical methods.

Given the variation of the value of the preconsolidation pressure on samples from the same location and by applying the same method of determination, it is sustained the

requirement to obtain and test at least 3 oedometer samples for each level of interest from the stratification.

Positioning the value of the preconsolidation pressure in the coordinates of the graph of the characteristic curve, obtained in the laboratory by means of the oedometer test, is also necessary to make the correction of the compression-porosity curve. This correction makes sense due to the unfavorable effects specific of the efforts path (processes made from the in situ drilling up to the sample loading in the oedometer apparatus) on the soil sample structure, on the porosity index and implicitly of the compression-porosity curve. Based on the compression-porosity curve, the value of the indices that characterize the compressibility of the layer from which the soil sample was extracted is determined. Deformations determined on the basis of corrected curves are smaller than those obtained on the uncorrected curves (Duncan et al. 1991). Therefore, the correct determination of the preconsolidation pressure is the key in obtaining real values of the compressibility indices of the soil samples (Katarzyna & Alojzy 2010). The correction of the compression-porosity curve can be done by using the Casagrande procedure for normally consolidated soils and by the Schmertman procedure for super-consolidated soils, with the mention that both procedures borrow reciprocal steps which are based on the in situ porosity or based on the approximated in situ porosity that is determined on the basis of the low of compaction applied by inverse calculation.

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