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FLOW-PUMP TECHNIQUE AS A CONSTANT VELOCITY METHOD OF FLOW MEASURMENT IN SOFT ORGANIC SOILS

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ABSTRACT

In this paper the results of the relationship between pore pressure differences and time obtained in laboratory flow-pump technique tests in soft organic soils are presented.

The Soil-Water Characteristic is necessary to predict and calculate the real amount of vertical and horizontal deformations which depend on consolidation process and are relatively large in soft organic soils. The consolidation curve is changeable with the different values of load. In the deformation process of soil skeleton, under loading, the porosity decreases and causes the changes of permeability characteristics. Considerable differences in flow parameters between soft, cohesive and uncohesive soils demand to use various methods of water flow measurement in the subsoil under the engineering constructions. The laboratory methods for permeability measurement should model the main course of in-situ flow for fully saturated soils.

Because of very week organic soils structure and specific properties, such as, high porosity, low shear strength and high initial permeability which decrease during consolidation, the method of flow measurement should be suitable. The results obtained in flow-pump laboratory tests indicated that the constant velocity method is very optimized and proper to measure the flow parameters in soft peats.

Key words: nonlinear water flow characteristic, consolidation process, deformations, organic soils, peat.

INTRODUCTION

The soft organic soils are very problematic for investments, because of their specific properties: high vertical and horizontal deformations which occur during and after the construction period, low initial shear strength which can causes difficulties to achieve the embankment stability, high initial permeability which changes drastically during the loading are the main engineering task to solve and improve during the investment. There are a few method of improvement. The most common and relatively cheap is loading applied by stages or consolidation.

The consolidation process depends on distribution of water pore pressure which is connected to permeability [10, 11]. To design and prognosis engineering constructions on soft organic soils the analysis of value and course of subsoil deformations and water pore pressure should be preceded [9].

Most of the consolidation theories are based on Terzaghi assumptions. The previous works have shown that the linear Darcy's law is acceptable only for uncohesive soils. Some of the authors indicated that water flow characteristics in soft subsoils are non-linear in different stress values [2, 5, 6, 7, 9, 11]. In soft organic soils, such as peats, the in-situ value of hydraulic gradient is very low. To verify the validity of Darcy's law at very low gradients is almost impossible [9, 11, 17]. Also it has been proved that to describe the hydraulic conductivity characteristics the prelineary and postlineary phases should be considered [10, 11]. The non-linear prelineary phase characterizes flow at very low hydraulic gradient which usually appears in situ (fig. 1). In high values of hydraulic gradient the non-linear postlineary phase appears, which can be only possible with the hydraulic penetrate [13].

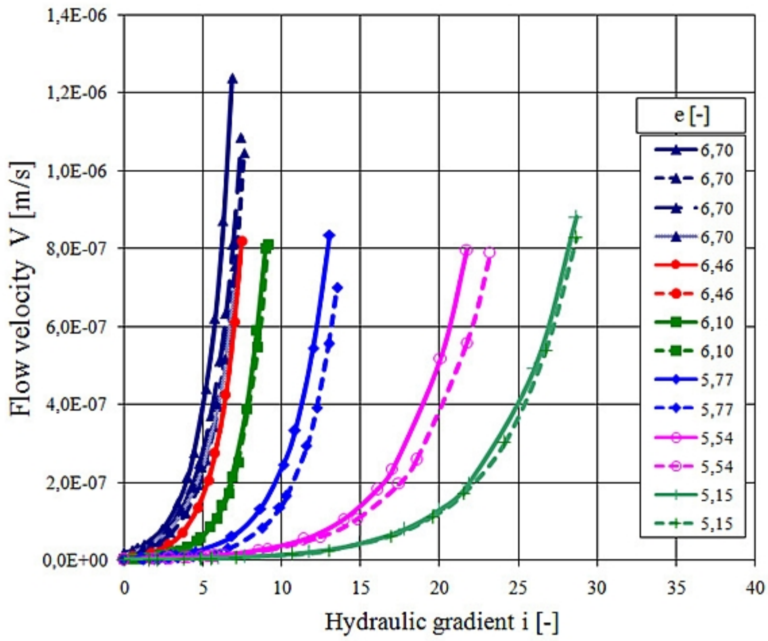

Figure 1. – The relationship between flow velocity and hydraulic gradient in the prelineary phase[13]

To obtain the water flow characteristics in soft organic soils the relationship between flow velocity and hydraulic gradient should be found. In the flow - pump technique, the discharge capacity "Q" of water flow is constant but the difference of pressure "ΔH" is measured during laboratory testing [13].

The Flow-Pump Technique

A lot of different methods, direct and indirect, can be used to measure the water flow in saturated soils in the laboratory tests.

It is very important to choose a proper method because of the reliability of the test results, repeatability and reproducibility of the test results, the reconstruction of reflection in-situ conditions, difficulties and costs of the tests. In order to take into consideration these factors it is recommended to use direct laboratory methods to eliminate additional calculation errors [11].

Generally there are two laboratory methods: constant-head method and falling-head method. Nevertheless in the last years with the technology evaluation the flow-pump technique was considered, initiated by Olsen [14].

In the flow-pump technique the value of pore pressure differences is measured till the value of flow velocity is constant. The value of permeability coefficient can be written by formula:

$$k = \frac{V}{i} \text{ [m/s]} \tag{1}$$

where: V - flow velocity [m/s], i - hydraulic gradient [-].

The forerunner of the constant velocity method of flow measurement was Olsen in 1966 [14]. The method of laboratory tests proposed by Olsen is completely different from the constant-head and falling-head methods. In the Olsen Apparatus the vertical flow can be measured in two ways, from the bottom to the top and backwards. Also the wide values of hydraulic gradient can be applied, which is very useful to precise the permeability coefficient in soft organic soils, where the loading is little and the water content is high. The Olsen Apparatus make it possible to control soil settlement under the loading and making test in fully saturated conditions (fig.2).

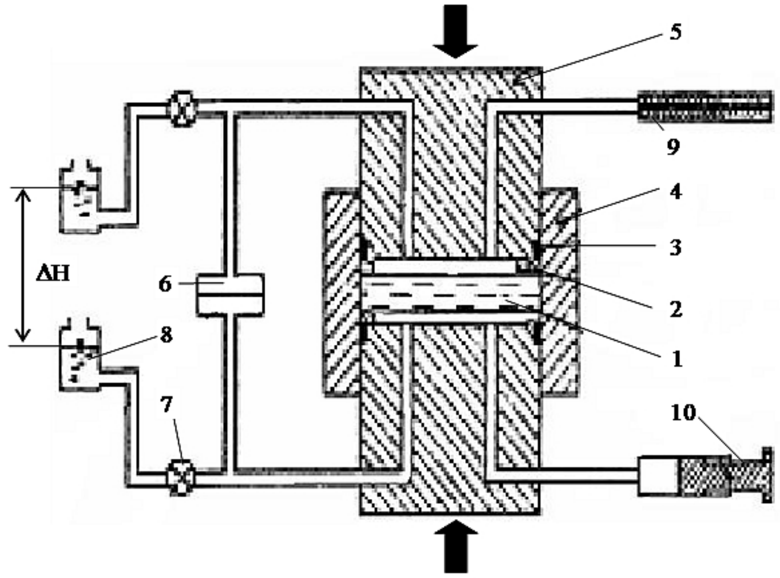

Figure 2. – Olsen Apparatus (1966): 1 – soil sample in the cell, 2 – porous ceramic disc, 3 – seal ring, 4 – steel ring, 5 – steel piston, 6 - difference pressure controller, 7 - valve, 8 – water dish, 9 – measure capillary, 10 - piston pump [14].

To measure the permeability coefficient in Olsen Apparatus two different methods can be used:

1. To enforce difference of pore pressure and to measure the flow force
2. To enforce flow and to measure pore pressure differences.

To point out the hydraulic gradient the second method is much more convenient. This method gives the opportunity to generals the constant flow velocity by using special pump. The flow-pump technique was accepted by ASTM Standard Test Method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using Flexible Wall Permeameter (D5084-90) in 1985.

In 1991 Olsen et al. used the constant flow velocity method, which is able to controls the flow velocity depends on effective stress or void ratio for fully saturated soils samples, isotropic consolidated and unloading [15]. Next, in 1994 Olsen et al. [16] additionally install two parallel pumps to make the same flow by two opposite ends of soil sample (fig.3).

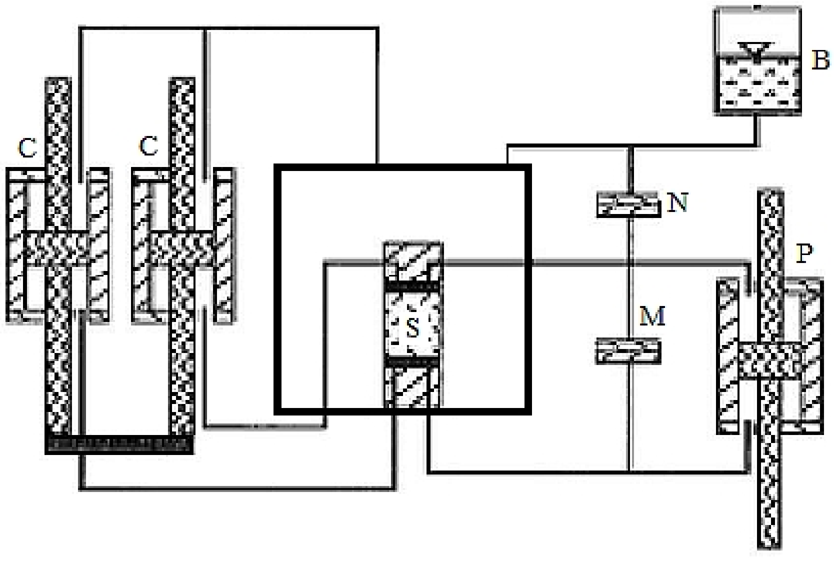

Figure 3. – Triaxial system for fully saturated soil sample under isotropic strain: S – soil sample, B – highly-pressure frame, P - pump, CC – additional pumps, M – pressure controller, N – additionally installed difference pressure [16].

In last few years the flow-pump technique was modernized. Shackelford and Glade (1994) made the system founded by Olsen (1966), Olsen et al. (1994) and Aiban & Znidarcic (1989), with two pumps for testing ash (fig.4).

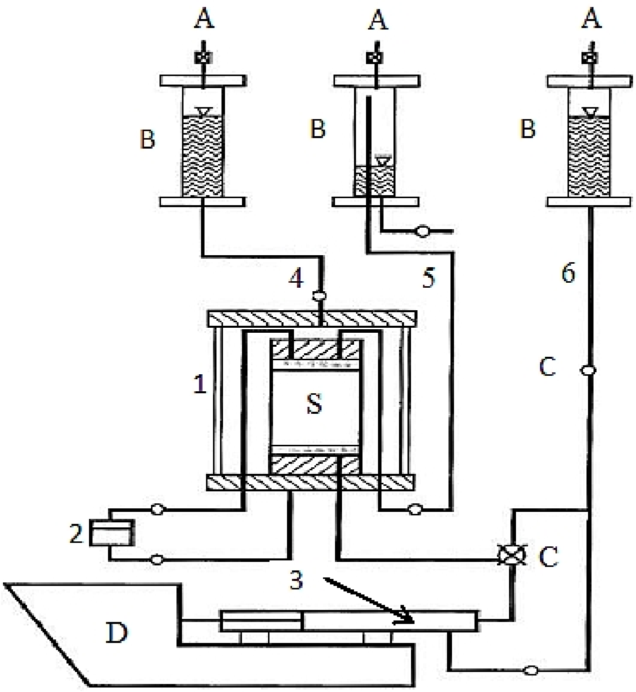

Figure 4. – Scheme of constant, controlled velocity method with two pumps for testing ash: A- pressure, B – water reinforce , C – valve, D - pump engine, S – soil, 1 – cell, 2 – difference pressure gauge, 3 – piston cell, 4 – cell reinforce, 5 – soil sample reinforce, 6 – flow-pump reinforce [17].

Bartholomeeusen, Znidarcic, Hwang, Sills (2001) were testing clays to find the relationship between permeability coefficient and void ratio depending on effective stress using flow-pump technique (fig. 5).

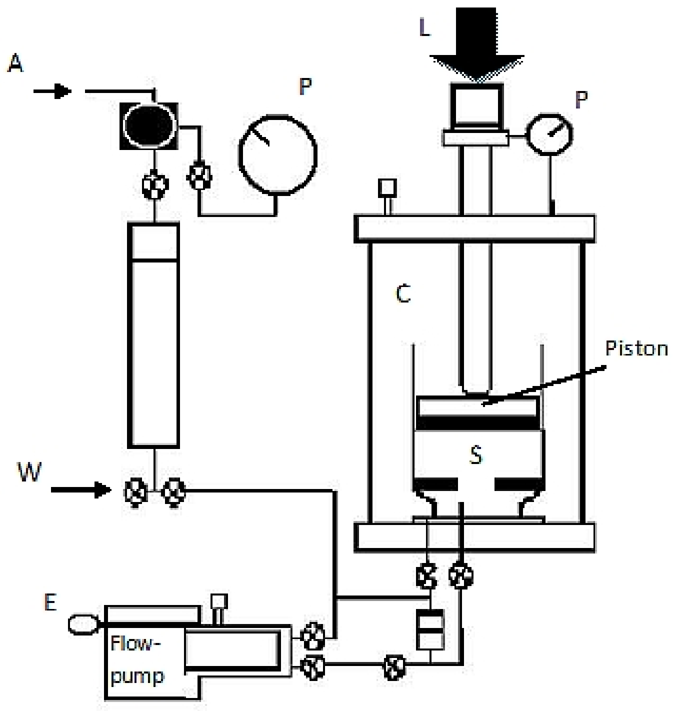

Figure 5 . – Flow-pump system: A- air, C- traxial cell, E – engine, L –load, P –pressure reducer, S- soil sample, W - water [2].

The flow-pump technique is also used in Geotechnical Department, Warsaw University of Life Sciences. This technique is working with GeoSys System, that can read and write the test results in different options. This controlled-measured system is the much optimized method for direct laboratory tests. The main advantage of a direct, flow-pump technique is the time in which the low, in-situ hydraulic gradients can be applied [1, 9, 10, 14, 15]. Also the flow-pump technique, called sometimes "controlled flow system”, with the triaxiall cell is able to measure very low values of hydraulic gradient with the control of effective vertical stress, cell pressure, back pressure, value of drainage, displacements for fully saturated soft organic soils.

THE METHOD OF INVESTIGATION

The flow-pump technique was used to describe the relationship between flow velocity and hydraulic gradient for different values of vertical effective stress in soft organic soils, peats.

The whole flow-pump system used to research the flow characteristics in soft, very changeable, organic soils is shown on figure 6.

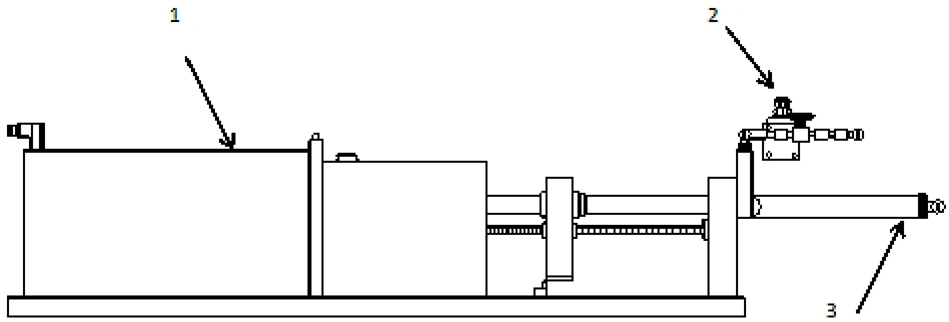

Figure 6. – The Flow-pump system: 1 – triaxiall cell, 2 – flow-pump, 3 - difference pressure gauge, 4 – steering panel, 5 – registration system, 6 – writing system, 7 – vertical movement gauge, 8 – soil sample, 9 – load piston, 10 - valve, 11 – cell pressure gauge, 12 – soil pressure gauge [9].

The pump pressing the water to the soil sample is connected with steering panel and to the traxiall cell. Nevertheless this system can be changed depends on different tests.

The receiver consist step engine with changeable movement, difference gauge and piston cell filled in with water (fig. 7). The piston diameter is equal 10mm and the length is 180mm. This receiver is able to press, and also to suck the water in the limited values of speed.

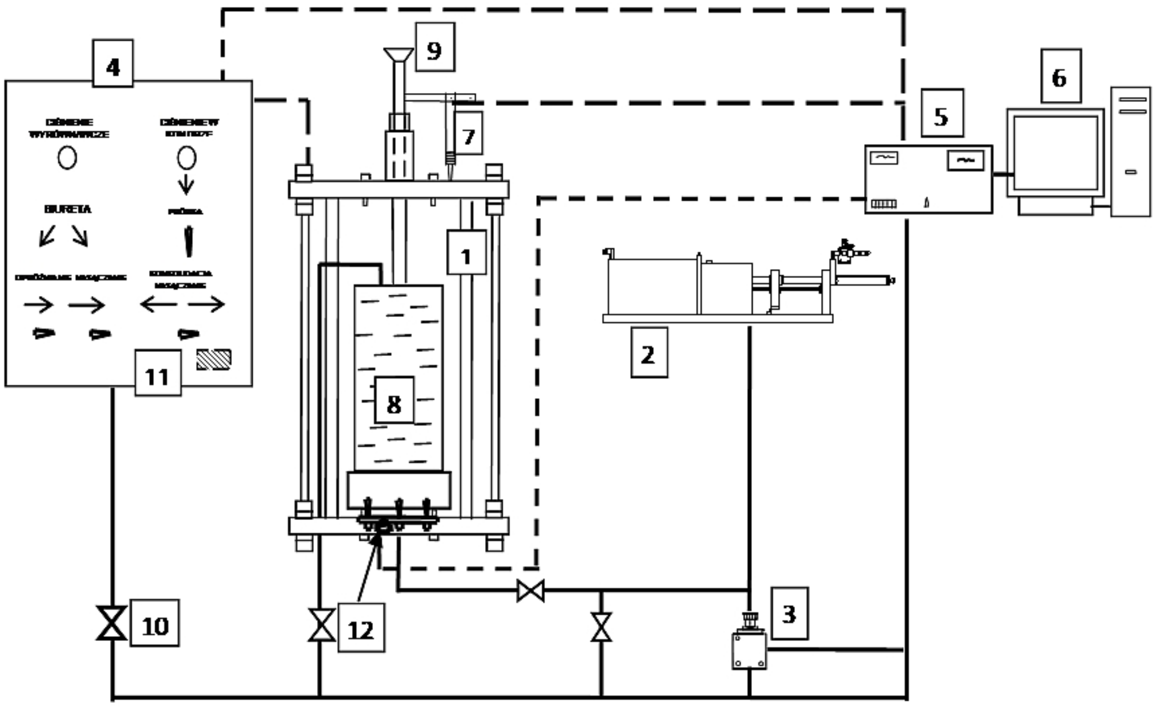

Figure 7. – The Flow-pump receiver VRDM 397/50 LWC: 1- step engine, 2- difference pressure gauge, 3 – piston cell [9].

The controlled-measured system is leaning on the constant velocity method, which controlled the time during the test and also the value of the total flow with the accuracy of 0.001cm^3. On the recording display the value of difference pressure is shown. The difference pressure gauge, type DP 15-52, is able to measure the pressure in the range from 0 to 150kPa with the accuracy of 0.1kPa.

There are few stages of the investigation: saturation, consolidation and flow test.

The saturation is possible when the all system is vent. Fully soil saturation is possible with the back pressure method, using Boyle Law about the liquid compressibility and Henre Law about phenomena of the gas resolve in water.

The tests were performed in isotropic stress condition with the soil saturation determinate by index B:

$$B = \frac{du}{ds} \tag{2}$$

where:

du – increase of back pressure

ds – the change of pressure differences in soil sample and cell.

To call out the back pressure, the same pressure was applied to the bottom and to the top of the soil sample. The whole tests were performed with the fully saturated samples, with the B index more than 0.92.

The next stage of the tests was consolidation process in an isotropic conditions, $\sigma_h = \sigma_v$.

The soils samples were collected from the same in situ localization and consolidated with different vertical effective stress.

After adding in situ stress and connecting the whole flow-pump system, the volume change occurred because the water outflows from the soil sample. During the consolidation process the back pressure was obtained and the vertical stress was induced by load piston (9).

The whole changes, such us: volume change, vertical displacements, back pressure and cell pressure induced by consolidation strain during the test were register in time.

When the volume change is stability the consolidation process is over. But the test can be performed due to creep process, which is very common in soft organic soils. To check up the end of consolidation strain, the scheme of compression curves and scheme of volume changes should be done (fig. 8 & 9).

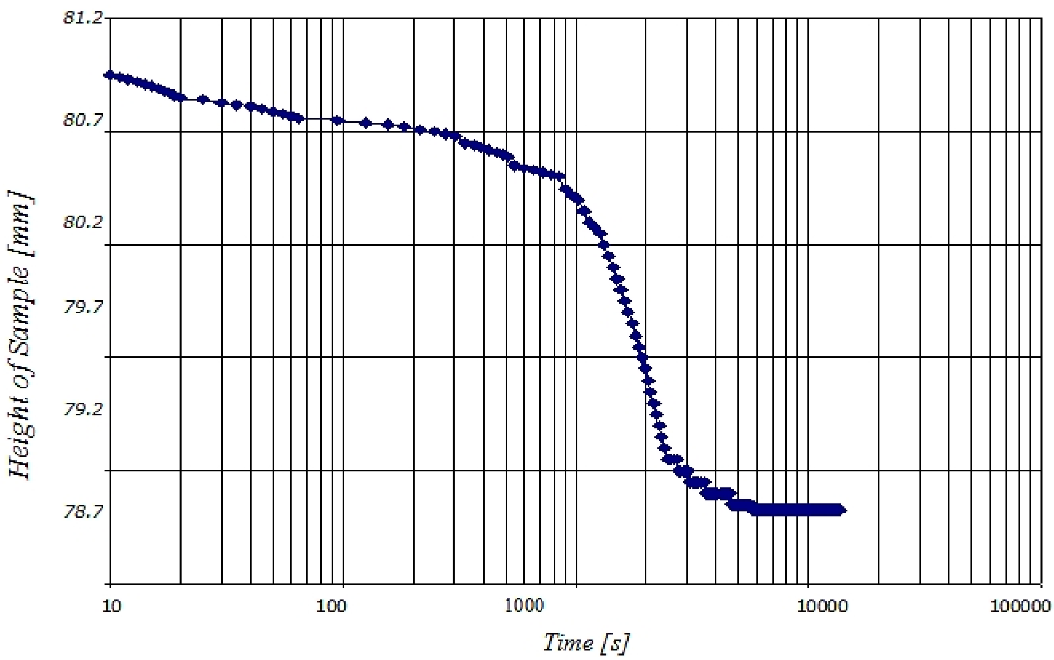

Figure 8. – Compression curve for vertical effective stress 25kPa.

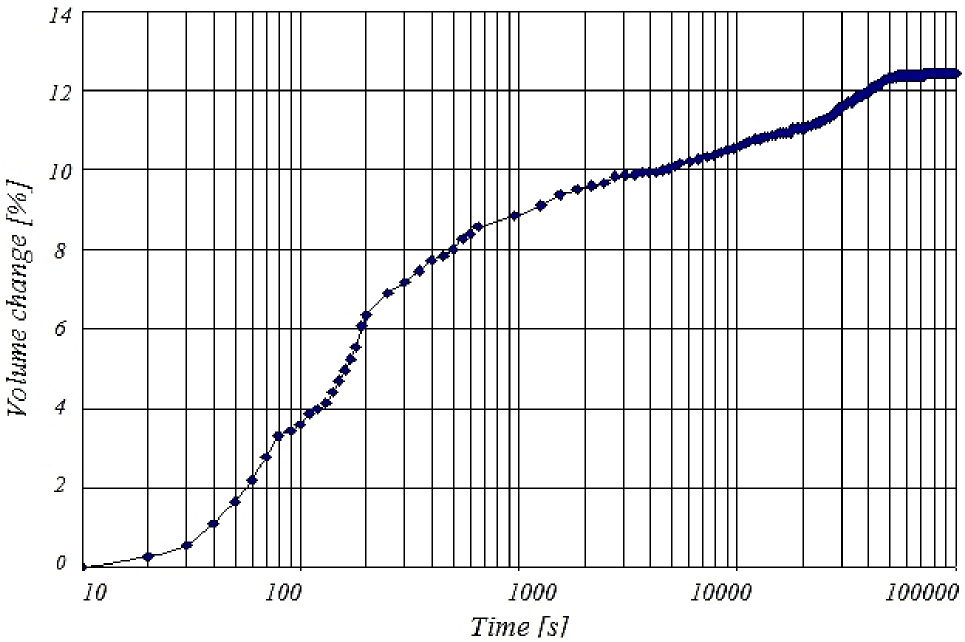

Figure 9. – Scheme of volume change for vertical effective stress 25kPa.

The whole test with flow-pump technique can be divided into a few stages. The next stage, after preparing soil sample and consolidation test, is the measurement of the pressure difference on the top and bottom of the sample by the difference pressure gauge, (3). The water flow is forced by flow-pump piston. First, the value of the water flow has to be chosen. The choice depends of the permeability value initial determinate by in-situ test, during recruitment. Nevertheless, the test should be started from the lowest value of the flow volume.

During the whole test, the back pressure and the system air tightness should be controlled. The water flow from the flow-pump piston cell to the soil sample placed in triaxiall cell is able by small- diameter pipes. The bottom of the soil sample is connected to the one of the ends of the difference pressure gauge. The top of the soil sample is connected to the second end of the difference pressure gauge (3).

The flow-pump is connected from the one side to the steering panel (4) and from the other to the bottom of the soil sample placed in the triaxial cell (1). With the help of this connection, during the flow-pump test the same back pressure is delivered as during the consolidation test. The water pressure flowing to and also out flowing from the soil sample is measured by difference pressure gauge (3), which is the main element of flow-pump apparatus VRDM 397/50 LWC (2).

During the laboratory test, water with the constant velocity flow from the piston cell (2) thought difference pressure gauge (3) to the bottom of the soil sample. In connection with it, the hydraulic pressure on the bottom of the soil sample increase gradually and the difference pressure between the bottom and the top of the soil sample is measured. When the water pore pressure is higher than the energy of amidst molecule influence, the water flow occurs.

During one test, a few different values of discharge capacity “Q” were set. The difference of pressure “ΔH” and time “t” is measured during laboratory testing.

On the steering panel value of discharge capacity “Q” can be from 0.001 to 80 cm^3/h. This receiver is able to press, and also to suck the water in the limited values of speed. The registration system (5) controls the time and the total value of flow with the accuracy to 0.001 cm3, as well as difference of pressure “ΔH” on two ends of the soil sample. Additionally the steering panel (4) controls back pressure and the soil sample pressure. Also the steering panel (4) is equip in two channels from the top and the bottom of the soil sample, that let to register and control data test by program GeoSys 2000.

The data tests are record by computer and transport to calculating program to be changed to SI units.

THE ADVANTAGES OF THE FLOW-PUMP TECHNIQUE AS A CONSTANT VELOCITY METHOD OF FLOW MEASURMENT IN SOFT ORGANIC SOIL

To point out the flow characteristics in different types of soils in laboratory conditions, the direct and indirect methods are used. To make the proper choice of the methods needs to analyses a few elements such as: reliability of the test results, recurrence and reproduction of the test results, the level of the reconstruction of in-situ conditions, advanced procedure and costs [4]. Regarding to this important elements, it is indicated to use direct methods to avoid additional elements connected with miscalculating.

In the laboratory tests, it is important to minimalism errors that can effect on the test results during flow measurement in soft organic soils. The main errors can be: non-representative soil sample, non-reproduction soil sample, the preparation of the soil sample, the installation of the soil sample in the cell, the way and direction of the flow, the evolution of the micro-organisms, the air in the soil sample, too high value of the hydraulic gradient, the change of the soil sample capacity during loading, the change of the temperature during the test.

The flow-pump technique as a constant velocity method of flow measurement in soft organic soils used with triaxiall cell conditions with GeoSys Programme has followed advantages:

- the soil samples can be representatives and reproduced
- the preparation of the soil sample is relatively easy, only the flow through elastic walls should be reduced by rubbing of silicon
- the installation of the soil sample in the traxiall cell is common
- the way and the direction of the flow is only vertical
- the evolution of the micro-organisms is almost impossible because the time of the test is very short, for example for $k > 10^{-8}$ m/s – time of the measurement is a few minutes, for $10^{-10} \leq k \leq 10^{-11}$ m/s – time of the measurement is a few hours and for $10^{-12} \leq k \leq 10^{-13}$ m/s time of the measurement is few days
- the air in the soil sample is impossible because of the fully saturation before consolidation process and the back pressure control during the whole test
- too high value of the hydraulic gradient is not need because in the flow - pump technique, the discharge capacity "Q" of water flow is constant and can be set in the range from 0.001 to 80 cm3/h
- also the difference pressure gauge, type DP 15-52, is able to measure the pressure in the range from 0 to 150kPa with the accuracy of 0.1kPa
- the change of the soil sample capacity during loading is controlled by steering panel (4)
- the change of the temperature during the test can be controlled.

THE RELIABILITY OF LABORATORY TEST RESULTS

To verification the reliability of laboratory test results and to analysis the possibility of trade on these dates in obtaining flow characteristics that determine consolidation process, the estimation of uncertainty of the water flow velocity data were done.

The analysis of uncertainty of hydraulic gradient test results for two; the same soils samples were performed. The specifics of organic soils substratum calls for a series of repeated tests. More than once this condition cannot be met because of the financial, time and technique limits. Hence, in the statistical analysis of the laboratory tests results the required measurement adaptation, the reliability opinion, and the uncertainty analysis should be done.

Besides, the influences of the temperature and soil sample diameter were tested.

The estimations were performed for a couple of the same soil sample data’s tested in the same laboratory conditions. The range, variation, deviation, recurrence and the uncertainties were defined.

The laboratory tests were performed on representative peat samples from “Campus SGGW” site. There were 349 flow-pump tests in 13 different stress conditions realized.

Some of the laboratory test results with the statistical analyze is presented in tables 1 to 7.

Table 1.– Test results for 10kPa loading with statistical analyzes.

Q [m^3/s]	V [m/s]	ΔH 6.10 [kPa]	ΔH 1.10 [kPa]	Interval [kPa]	Variation [kPa]
1,667E-11	1,48E-08	**0,00**	**0,00**	0,00	0,00000
2,222E-11	1,97E-08	**0,48**	**0,45**	0,03	0,00045
2,778E-11	2,47E-08	**0,76**	**1,00**	0,24	0,02880
5,556E-11	4,93E-08	**1,20**	**1,40**	0,20	0,02000
1,111E-10	9,86E-08	**2,20**	**2,30**	0,10	0,00500
1,667E-10	1,48E-07	**3,10**	**3,00**	0,10	0,00500
2,222E-10	1,97E-07	**3,64**	**3,60**	0,04	0,00080
2,778E-10	2,47E-07	**4,01**	**4,00**	0,01	0,00005
4,167E-10	3,85E-07	**4,70**	**4,80**	0,10	0,00500
5,556E-10	4,93E-07	**5,20**	**5,20**	0,00	0,00000
8,333E-10	7,40E-07	**5,70**	**5,70**	0,00	0,00000
1,389E-09	1,23E-06	**6,22**	**6,40**	0,18	0,01620
			average variation		0,00678
			standard deviation		0,08231
			recurrence		0,23047
			optimistic uncertainty		**0,16133**
			peimistic uncertainty		**4,11800**
			uncertainty e_p		**0,46913**
				TEST F	***99%***
				TEST T	***95%***

Table 2. – Test results for 15kPa loading with statistical analyzes.

Q [m^3/s]	V [m/s]	ΔH 2.15 [kPa]	ΔH 6.15 [kPa]	Interval [kPa]	Variation [kPa]
2,78E-12	2,65E-09	**0,00**	**0,00**	0,00	0,00000
1,67E-11	1,59E-08	**0,30**	**0,45**	0,15	0,01125
2,78E-11	2,65E-08	**1,40**	**1,60**	0,20	0,02000
5,56E-11	5,31E-08	**2,20**	**2,50**	0,30	0,04500
1,11E-10	1,06E-07	**3,10**	**3,30**	0,20	0,02000
1,67E-10	1,59E-07	**4,00**	**4,20**	0,20	0,02000
2,22E-10	2,12E-07	**4,50**	**4,80**	0,30	0,04500
2,78E-10	2,65E-07	**4,80**	**5,20**	0,40	0,08000
4,17E-10	3,98E-07	**5,58**	**5,80**	0,22	0,02420
5,56E-10	5,31E-07	**5,96**	**6,30**	0,34	0,05780
8,33E-10	7,96E-07	**6,47**	**6,70**	0,23	0,02645
			average variation		0,03179
			standard deviation		0,17830
			recurrence		0,49924
			optimistic uncertainty		**0,34947**
			peimistic uncertainty		**4,42134**
			uncertainty e_p		**0,52241**
				TEST F	***92%***
				TEST T	***82%***

Table 3. – Test results for 20kPa loading with statistical analyzes.

Q [m³/s]	**V [m/s]**	**ΔH 5.20 [kPa]**	**ΔH 11.20 [kPa]**	**Range [kPa]**	**Variance [kPa]**
2,222E-12	1,973E-09	**0,00**	**0,00**	0,00	0,000000
2,778E-12	2,466E-09	**0,60**	**0,22**	0,38	0,072200
5,556E-12	4,932E-09	**0,80**	**0,76**	0,04	0,000800
1,111E-11	9,865E-09	**1,20**	**1,25**	0,05	0,001250
1,667E-11	1,480E-08	**1,86**	**1,90**	0,04	0,000800
2,222E-11	1,973E-08	**2,28**	**2,60**	0,32	0,051200
2,778E-11	2,466E-08	**2,43**	**2,60**	0,17	0,014450
5,556E-11	4,932E-08	**2,78**	**3,20**	0,42	0,088200
1,111E-10	9,865E-08	**3,55**	**3,90**	0,35	0,061250
1,667E-10	1,480E-07	**4,20**	**4,70**	0,50	0,125000
2,222E-10	1,973E-07	**4,80**	**5,30**	0,50	0,125000
2,778E-10	2,466E-07	**5,30**	**5,80**	0,50	0,125000
4,167E-10	3,61E-07	**6,00**	**6,00**	0,00	0,000000
5,556E-10	4,932E-07	**6,50**	**6,80**	0,30	0,045000
8,333E-10	7,398E-07	**7,22**	**7,30**	0,08	0,003200
			average variation		0,04756
			standard deviation		0,21807
			recurrence		0,61061
			optimistic uncertainty		**0,42743**
			peimistic uncertainty		**4,52867**
			uncertainty e_p		**0,50925**
				TEST F	***84%***
				TEST T	***83%***

Table 4. – Test results for 25kPa loading with statistical analyzes.

Q [m³/s]	**V [m/s]**	**ΔH 9.25 [kPa]**	**ΔH 10.25 [kPa]**	**Range [kPa]**	**Variance [kPa]**
2,222E-12	1,17E-09	**0,00**	**0,00**	0,00	0,000000
2,778E-12	1,46E-09	**0,87**	**0,92**	0,05	0,001250
5,556E-12	2,92E-09	**1,90**	**1,48**	0,42	0,088200
1,111E-11	5,84E-09	**2,10**	**1,72**	0,38	0,072200
1,667E-11	8,77E-09	**2,20**	**2,06**	0,14	0,009800
2,222E-11	1,17E-08	**2,33**	**2,22**	0,11	0,006050
2,778E-11	1,46E-08	**2,60**	**2,66**	0,06	0,001800
5,556E-11	2,92E-08	**3,60**	**3,39**	0,21	0,022050
1,111E-10	5,84E-08	**5,40**	**5,12**	0,28	0,039200
1,667E-10	8,77E-08	**7,30**	**6,83**	0,47	0,110450
2,222E-10	1,17E-07	**8,00**	**7,66**	0,34	0,057800
2,778E-10	1,46E-07	**8,57**	**8,00**	0,57	0,162450
5,556E-10	2,92E-07	**9,50**	**9,00**	0,50	0,125000
8,333E-10	4,38E-07	**10,30**	**9,50**	0,80	0,320000
			average variation		0,07259
			standard deviation		0,26942
			recurrence		0,75439
			optimistic uncertainty		**0,52807**
			peimistic uncertainty		**6,48342**
			uncertainty e_p		**0,67088**
				TEST F	***83%***
				TEST T	***82%***

Table 5. – Test results for 30kPa loading with statistical analyzes.

Q [m^3/s]	**V [m/s]**	**ΔH 2.30 [kPa]**	**ΔH 6.30 [kPa]**	**Range [kPa]**	**Variance [kPa]**
2,22E-12	2,12E-09	**0,00**	**0,00**	0,00	0,000000
2,78E-12	2,65E-09	**1,20**	**1,60**	0,40	0,080000
5,56E-12	5,31E-09	**2,00**	**2,20**	0,20	0,020000
1,11E-11	1,06E-08	**2,80**	**3,00**	0,20	0,020000
1,67E-11	1,59E-08	**3,80**	**3,85**	0,05	0,001250
2,22E-11	2,12E-08	**4,00**	**4,20**	0,20	0,020000
2,78E-11	2,65E-08	**4,40**	**4,50**	0,10	0,005000
5,56E-11	5,31E-08	**6,30**	**6,70**	0,40	0,080000
1,11E-10	1,06E-07	**8,60**	**9,00**	0,40	0,080000
1,67E-10	1,59E-07	**10,20**	**11,00**	0,80	0,320000
2,22E-10	2,12E-07	**12,00**	**12,65**	0,65	0,211250
2,78E-10	2,65E-07	**12,80**	**13,40**	0,60	0,180000
5,56E-10	5,31E-07	**15,00**	**15,80**	0,80	0,320000
8,33E-10	7,96E-07	**16,00**	**17,10**	1,10	0,605000
		average variation			0,13875
		standard deviation			0,37249
		recurrence			1,04298
		optimistic uncertainty			**0,73008**
		peimistic uncertainty			**10,53132**
		uncertainty e_p			**1,09339**
				TEST F	***85%***
				TEST T	***84%***

Table 6. – Test results for 40kPa loading with statistical analyzes.

Q [m^3/s]	**V [m/s]**	**ΔH 5.40 [kPa]**	**ΔH 14.40 [kPa]**	**Range [kPa]**	**Variance [kPa]**
5,556E-13	5,68E-10	**0,00**	**0,00**	0,00	0,000000
2,222E-12	1,14E-09	**1,42**	**1,60**	0,18	0,016200
5,556E-12	2,27E-09	**2,75**	**2,90**	0,15	0,011250
1,111E-11	5,68E-09	**3,62**	**3,70**	0,08	0,003200
1,667E-11	1,14E-08	**4,10**	**4,10**	0,00	0,000000
2,222E-11	2,27E-08	**4,40**	**4,23**	0,17	0,014450
2,778E-11	2,84E-08	**5,60**	**5,46**	0,14	0,009800
5,556E-11	5,68E-08	**8,60**	**8,19**	0,41	0,084050
1,111E-10	1,14E-07	**10,90**	**9,98**	0,92	0,423200
1,667E-10	1,70E-07	**13,00**	**13,00**	0,00	0,000000
2,222E-10	2,27E-07	**14,60**	**15,00**	0,40	0,080000
2,778E-10	2,84E-07	**16,00**	**16,50**	0,50	0,125000
5,556E-10	5,68E-07	**19,20**	**20,50**	1,30	0,845000
8,333E-10	8,51E-07	**21,00**	**22,00**	1,00	0,500000
		average variation			0,15087
		standard deviation			0,38842
		recurrence			1,08757
		optimistic uncertainty			**0,76130**
		peimistic uncertainty			**13,51011**
		uncertainty e_p			**1,35188**
				TEST F	***87%***
				TEST T	***96%***

Table 7. – Test results for 40kPa loading with statistical analyzes.

Q [m^3/s]	V [m/s]	ΔH 9.50 [kPa]	ΔH 10.50 [kPa]	Range [kPa]	Variance [kPa]
2,22E-12	1,17E-09	**0,00**	**0,00**	0,00	0,0000
2,78E-12	1,46E-09	**2,34**	**2,10**	0,24	0,0288
5,56E-12	2,92E-09	**2,75**	**2,55**	0,20	0,0200
1,11E-11	5,84E-09	**4,98**	**4,45**	0,53	0,1405
1,67E-11	8,77E-09	**7,35**	**6,00**	1,35	0,9112
2,22E-11	1,17E-08	**11,22**	**9,00**	2,22	2,4642
2,78E-11	1,46E-08	**13,62**	**13,00**	0,62	0,1922
5,56E-11	2,92E-08	**20,04**	**19,00**	1,04	0,5408
1,11E-10	5,84E-08	**28,00**	**26,00**	2,00	2,0000
1,67E-10	8,77E-08	**33,50**	**31,00**	2,50	3,1250
2,22E-10	1,17E-07	**39,80**	**35,00**	4,80	11,5200
2,78E-10	1,46E-07	**50,10**	**38,00**	12,10	73,2050
5,56E-10	2,92E-07	**60,00**	**68,90**	8,90	39,6050
			average variation		10,28867
			standard deviation		3,20760
			recurrence		8,98127
			optimistic uncertainty		**6,28689**
			peimistic uncertainty		**37,97582**
			uncertainty e_p		**7,11712**
				TEST F	***98%***
				TEST T	***85%***

Based on the test results obtained from direct, modern flow-pump technique, the flow characteristics was written. After analysis, it was assumed that the flow velocity depend on hydraulic gradient and void ratio as follows:

$$V = f(i, e) \tag{3}$$

where:

i – hydraulic gradient,

e – void ratio.

The analysis of uncertainty of the laboratory tests results of the flow characteristics in peats was carried out on the whole set of the laboratory tests results. In table 8, the comparison of the uncertainty analysis of some laboratory tests results is presented, where s^2 is the average variation of the two the same representative samples, s is the standard deviation, r is the repeatability, e_p is the extended uncertainty assessed by two estimates: e_p' - estimated on the basis of standard deviation and e_p'' - estimated on the basis of total standard deviation [13].

Table 8. -The comparison of the uncertainty analysis of the laboratory tests results

Set's order	The number of analyzed sets		Value of load	The results of the uncertainty analysis					
	set A	set B	[kPa]	s^2	s	r	e_p'	e_p''	e_p
1	6.10	1.10	10	0,0068	0,0823	0,2305	0,1613	4,1180	0,4691
2	6.10	11.10	10	0,0320	0,1788	0,5008	0,3505	4,0633	0,4754
3	6.10	14.10	10	0,0232	0,1524	0,4268	0,2988	4,0839	0,4573
4	11.10	14.10	10	0,0362	0,1904	0,5331	0,3731	3,9360	0,4892
5	2.15	6.15	15	0,0318	0,1783	0,4992	0,3495	4,4213	0,5224
6	5.20	11.20	20	0,0476	0,2181	0,6106	0,4274	4,5287	0,5093
7	9.25	10.25	25	0,0726	0,2694	0,7544	0,5281	6,4834	0,6709
8	2.30	6.30	30	0,1388	0,3725	1,0430	0,7301	10,5313	1,0934
9	5.40	14.40	40	0,1509	0,3884	1,0876	0,7613	13,5101	1,3519
10	9.50	10.50	50	10,289	3,2076	8,9813	6,2869	37,9758	7,1171

Additionally the coherence tests were performed. Test F gives one side probability that data variations from set A and set B are not so different. Test T is performance to find permeability that two samples with the same average value comes from the same set.

The measure of uncertainty calculated for different values of loading is shown in table 9.

Table 9. -Uncertainty measurements values [13].

No.	Value of load σ_v' [kPa]	The uncertainty analysis results		
		e_p'	e_p''	e_p
1	10	0.16	4.12	0.47
2	15	0.35	4.42	0.52
3	20	0.43	4.53	0.51
4	25	0.53	6.48	0.67
5	30	0.73	10.53	1.09
6	40	0.76	13.51	1.35
7	50	6.29	37.97	7.12

DISCUSSION OF THE RESULTS

Observations of the consolidation process in soft organic soils demonstrate large values and a non-linear character of deformation and permeability. Therefore, the prediction of consolidation performance in organic subsoil should be carried out by methods which take into account the variation of soil parameters and large strains analysis.

Laboratory tests presented in this paper indicate that the value and non-lineary of flow velocity *V* depend on hydraulic gradient *i* and stress range, indicated by void ratio *e*.

It is important to note that the permeability parameters influence a lot on consolidation process in soft, very compressible and organic soils. Most of the organic soils do not have a significant stress history. Therefore, the laboratory method used to obtain flow characteristics should also consider the small, effective in-situ value of hydraulic gradient.

The flow-pump technique as a constant velocity method of flow measurement in soft organic soils is proposed as an optimal method to obtain repeatability, good estimated test results. The minimum coherence for test T, which is used to determine whether it is probable that two samples from the same population are with the same average value, is 82%. The minimum coherence for test F, which gives a one-sided probability that the variances of data in the first measurement set and in the second measurement set are almost the same, is 83%.

Statistical analyzes made on 349 flow-pump tests in 13 different stress conditions indicate that the average variation of the two the same representative samples for 10 and 15 kPa loading is equal less that 0,03 and increases with the loading value. Also residue statistical parameters, such as: standard deviation and the repeatability are on very low level, but with tendency of increase with the value of loading.

The extended uncertainty is less than 1.0 for the stress value up to 25kPa, about 1.5 for 30 and 40kPa, and $\mathbf{e_p}$ = 7.0 for stress value 50kPa.

CONCLUSIONS

The use of consolidation theory for the prediction of soil displacements under embankments requires taking into consideration the variable soil parameters which depend on the effective stress level and preconsolidation phenomena. This fact should be taken into consideration in the modeling process of consolidation performance.

Observations of the consolidation process in soft organic soils demonstrate large values and a non-linear character of deformation and flow characteristics. So, in the consolidation theory the permeability coefficient should be changed on flow velocity which depend mainly on hydraulic gradient and void ratio.

The test results show that the relationship between flow velocity and hydraulic gradient is always nonlinear.

The laboratory methods of permeability measurement should model the main course of in-situ flow. The flow-pump technique assure good estimated test results with the coherence of 82 ÷ 99%, what is very important to predict and calculate the real amount of vertical and horizontal deformations which depend on consolidation parameters and time.

Because of very week organic soils structure and specific properties, such as, high porosity, low shear strength and high initial permeability which decrease during consolidation, the optimized method for flow measurement in peats is flow-pump technique.

The flow-pump technique uses constant velocity method and traxiall cell. This is very comfortable and fast to use; that in the same apparatus it is able to unair the whole system, fully saturated with back pressure, consolidated, measured the flow velocity and even shear the soil sample at the end.

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