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The modified Rowe cell set for obtaining vertical and horizontal flow in soft organic soils **Zmodyfikowany system z komorą Rowe’a do wyznaczania przepływu w kierunkach pionowym i poziomym w słabonośnych gruntach organicznych**

Key words: modified Rowe cell set, vertical and horizontal flow, soft organic soils

Słowa kluczowe: zmodyfikowany system z komorą Rowe’a, przepływ w kierunku pionowym, przepływ w kierunku poziomym, słabonośne grunty organiczne

Introduction

The soft organic soils are very problematic for investments, because of their specific properties such as high vertical and horizontal deformations which occur during and after the construction period, low initial shear strength which can cause difficulties to achieve the embankment stability, high initial permeability which changes dramatically du-

ring the loading. The most common and relatively cheap method of soil improvement is consolidation caused by applied loading by stages.

The consolidation process depends on distribution of water pore pressure which is connected to permeability. To design and prognosis engineering constructions behaviour on soft organic soils the analysis of value and course of subsoil deformations and water pore pressure should be known (Malinowska, Szymański & Sas, 2011).

In loaded soft subsoil the significant consolidation process is observed. The consolidation process in this type of soil consists of stages: primary settlement (immediate and consolidation), second-

ry and tertiary settlement. Primary settlement is the result of immediate undrained elastic deformation of the subsoil under an applied load. However, secondary and tertiary settlement is the consequence of creep of material under the effective stress. It depends significantly on time and rheological properties of soil. Moreover, the rate of strain can increase and decrease during the creep phase as well as depends on the level of deviator stress (Den Haan & Edil, 1994).

During laboratory consolidation tests, it is very important to point the time and value of primary settlement and to indicate the beginning of secondary and tertiary settlement. Most of the analyses skip this task. The curve of the primary consolidation should be drawn with the specially notification the average value of time for the transition from primary to the secondary compression, that is called t_a , because the creep process is very noticeable in peat (Malinowska, 2016).

To obtain the water flow characteristics in soft organic subsoil during laboratory tests it is necessary to model the in situ conditions with consideration of very high water content, fully saturation, very high deformations both in vertical and horizontal direction, unpredictable effective stress and pore pressure range. One of the very precise method for obtaining flow characteristics is flow-pump technique (Malinowska, 2011), but it does not allow to perform the test in different flow and consolidation drainage directions.

Scholes, Clayton, Hoadley and Tiu (2007) are analysing the permeability anisotropy due to consolidation of compressible porous media using different models to shaped cross-sections in the

horizontal and vertical directions in the permeability apparatus, in radial testing configuration.

Vertical and horizontal laboratory permeability had been measurements in clay soils using the direct laboratory measurement of k_h and k_v , that may enable a better estimate of field consolidation behavior to be made in soils with either marked creep properties or a more pervious macro structure (Wilkinson & Shipley, 1972).

Also, Zhu and Yin (2004) are focused on the influence of the vertical and horizontal drainage smear effects into the consolidation process under ramp loading.

Conventional methods for obtaining permeability parameters

There are different methods that can be used to measure the permeability parameters in saturated soils in the laboratory. They are divided into direct and indirect methods.

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 test. That is why, it is recommended to use direct laboratory methods, such as constant head, falling-head and constant velocity method, to eliminate additional calculation errors. The comparison between these methods is presented in Figure 1.

Reliable calculations of deformation process depend on the precise description of water flow characteristics in the porous medium.

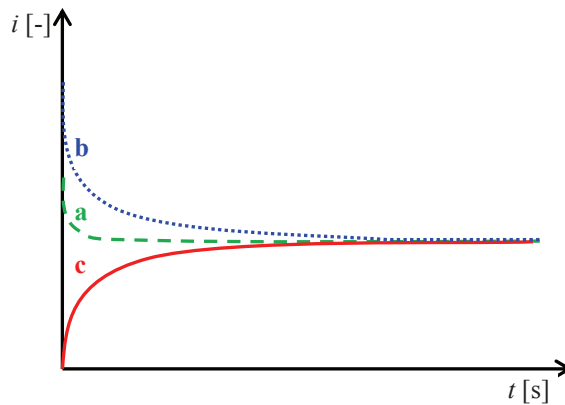


FIGURE 1. Different methods of permeability tests: (a) constant-head method; (b) falling-head method; (c) constant velocity method

RYSUNEK 1. Różne metody badanie przepływu: (a) metoda stałego gradient; (b) metoda zmiennego gradient; (c) metoda stałego przepływu

The Rowe cell is used to obtain consolidation or permeability parameters. The conventional Rowe cell is presented in Figure 2 (Rowe & Barden 1966;

Head, 1998). In this Rowe cell it is possible to control hydraulic load and to measure vertical deformations and pore water pressure during consolidation test

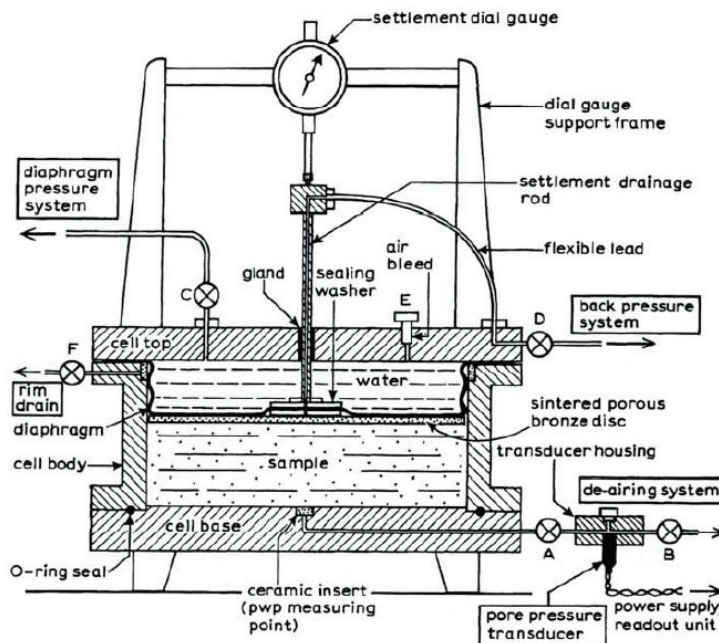


FIGURE 2. Main features of 250-mm diameter Rowe hydraulic consolidation cell (Head, 1998)
RYSUNEK 2. Główne cechy 250-milimetrowej komory Rowe'a (Head, 1998)

with the vertical or horizontal drainage in four conditions: -up or -down, -inside or -outside the soil sample. But, it is not possible to perform the consolidation test with the permeability measurements at the same soil sample and with the same conditions.

The modified Rowe cell set specification

The modified Rowe cell set (MRCS) is used to obtain consolidation and permeability parameters at the same time.

Using the MRCS it is possible to control pneumatic load, vertical and horizontal drainage and to measure vertical deformations and pore water pressure during the consolidation and permeability test. Also it is able to model different conditions of soil sample saturation (Fig. 3).

In the conventional Rowe cell set there are two device controllers, that stop

the set to apply two kinds of tests at the same time.

The modified Rowe cell set is provided by: vertical stress controller (ADC) – max. 3 MPa; two hydraulic device controllers (HDC) – max. 2MPa per 250 ml; pore water pressure sensor PWP – max. 1 MPa; vertical settlement sensor (S) – max. 50 mm; data logger (R); Rowe cell; software for data control (S) and data collection (csRowe).

In the modified Rowe cell set, the tested sample is loaded pneumatic by air pressure (ADC). The Rowe cell can be connected to back pressure unit, working in vertical (BP_v), or horizontal (BP_h) direction. The back (BP) pressure supports the pressure that is needed to make the effective stress. Also the direction of the drainage is simulated, at that time. Drainage of the sample is controlled all the time, and the pore pressure and volume change is measured automatically. Eight different types of drainage and load conditions can be applied in Rowe cell set.

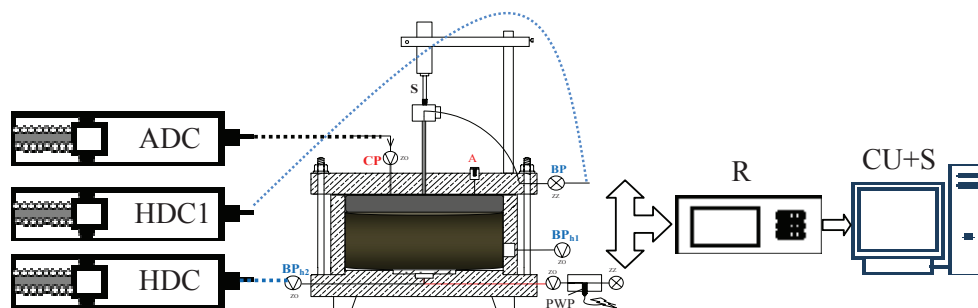


FIGURE 3. The modified Rowe cell set: ADC – air device controller; HDC – hydraulic device controller; $BP(v)$ – back pressure with vertical drainage; $BP(h)$ – back pressure with horizontal drainage; L – load; A – air; S – settlement; PWP – pore water pressure; R – recorder; CU+S – computer unit with software

RYSUNEK 3. Zmodyfikowany system z komorą Rowe'a: ADC – sterownik odpowietrznika; HDC – sterownik hydrauliczny; $BP(v)$ – ciśnienie wyrównawcze do zadania przepływu pionowego; $BP(h)$ – ciśnienie wyrównawcze do zadania przepływu poziomego; L – obciążenie; A – powietrze; S – osiadanie; PWP – czujnik ciśnienia wody w porach; R – rejestrator, CU+S – komputer z oprogramowaniem

The modified Rowe cell set is able to conduct consolidation tests in different stress conditions. It is possible to set precise effective stress by using air device controller (ADC) and hydraulic device controller 2 to set back pressure unit (BP).

The modified Rowe cell set is able to conduct also the permeability tests in different stress conditions. It is possible to set and hold precise effective stress by using air device controller (ADC) and provides the permeability tests by using two hydraulic controllers to set vertical or horizontal permeability tests.

Also, in the MRCS some modifications in the Rowe cell were done. The site back pressure that provides the horizontal permeability has been fixed in the half way on the wall cell. That causes the better horizontal conditions than it is in the conventional Rowe cell, where the site back pressure is on the top of the cell wall.

The test steps

The csRowe software provides two method of saturation, ramp or a step method. In the step method, the cell and back pressure are increased in steps until the desired B-value is achieved. In the ramp method, that had been chosen, the cell and back pressure are ramped and the B-check is carried out at regular intervals to see whether the required B-value has been reached. The saturation stage is end when the wanted B-value is reached. The B-value is calculated by raising the cell pressure by the required amount and the PWP is stabilized.

The consolidation stage consists of a undrained loading followed by a drained stage.

For every load increment (increasing or decreasing) the specimen is subject to an undrained and a drained phase. During the undrained stage, vertical stress is applied to the specimen with the drainage valve closed (BP) and consequently the increase in pore water pressure is monitored. This schedule is stopped when the PWP becomes stable. During the drained stage, the drainage valve (BP) is opened and kept the same, only the settlement value (S) is changing. The primary consolidation test is stopped when the pore water pressure reaches the predefined value 100% and the average value of time for the transition from primary to the secondary compression (t_a) is reached.

After consolidation stage, it is possible with MRCS to start immediately the permeability tests in obtained consolidation conditions. The vertical and horizontal permeability tests are able to done in one or two ways (up and down for vertical flow and outside or inside for horizontal flow). In the permeability stage, the hydraulic gradient is applied, and the flow velocity can be calculated. The program registers the volume change in both hydraulic device controllers. For the “downwards” vertical permeability test, the back pressure at the top (BP_{v1}) should be bigger than the one on the bottom (BP_{v2}), as it is shown in Figure 4. For the “upwards” vertical permeability test, the back pressure at the bottom (BP_{v2}) should be bigger than the one on the top (BP_{v1}). For the “inside” horizontal permeability test, the back pressure at the site (BP_{h1}) should be bigger than the one on the bottom (BP_{h2}), and smaller for the “outside” flow. The permeability stage is finished when the water volume in and out is parallel (Fig. 5).

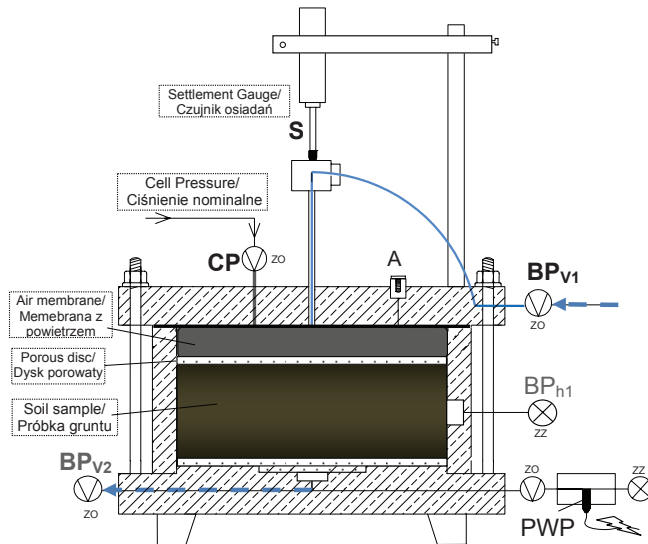


FIGURE 4. The Rowe cell set for vertical permeability test; S – settlement gauge; A – air flow; BP_{v1} , BP_{v2} – back pressure to set vertical permeability test; PWP – pore water pressure sensor
 RYSUNEK 4. Schemat komory Rowe’ a do badań przepływu pionowego: S – czujnik osiadań; A – odpowietrznik; BP_{v1} / BP_{v2} – ciśnienie wyrównawcze do zadania przepływu pionowego; PWP – czujnik ciśnienia wody w porach

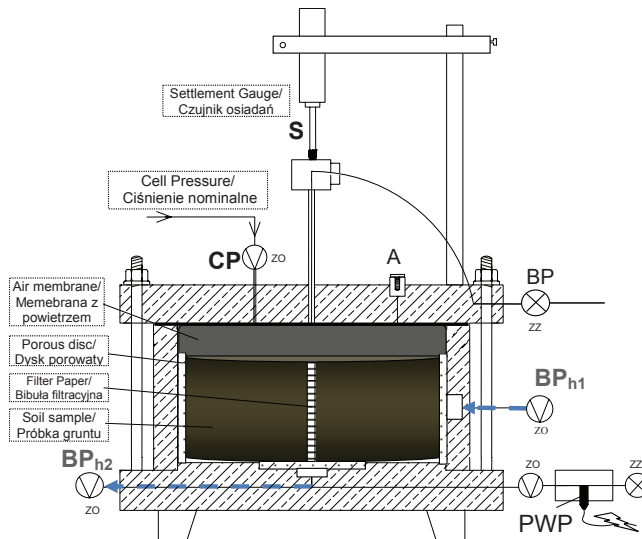


FIGURE 5. The modified Rowe cell set for horizontal permeability test; S – settlement gauge; A – air flow; BP_{h1} / BP_{h2} – back pressure to set horizontal permeability test; PWP – pore water pressure sensor
 RYSUNEK 5. Schemat zmodyfikowanej komory Rowe’ a do badań przepływu poziomego: S – czujnik osiadań; A – odpowietrznik; BP_{h1} / BP_{h2} – ciśnienie wyrównawcze do zadania przepływu poziomego; PWP – czujnik ciśnienia wody w porach

To obtain the tests all devices have to be connected. The pneumatic and hydraulic pressure controllers need to be connected to a PC serial port and to the modified Rowe cell.

In the modified Rowe cell set it is possible to apply free or equal strain to model *in situ* conditions of embankment or fundamental stress. And also, it is possible to conduct CRS or IL tests.

Summary and conclusions

Large values of deformation and a non-linear character of strain and permeability are expected in soft organic soils under loading. 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. The permeability characteristics are non-linear and depends on the effective stress value and hydraulic gradient. Because of very weak, anisotropy organic soils structure and specific properties, such as, high porosity, high water content, low shear strength, high deformation with very noticeable secondary and tertiary compression, high initial permeability which decrease during consolidation the optimized method for flow measurement in peats would be the constant flow velocity method with the vertical and horizontal drainages.

Two very important modifications were done in the (MRCS):

- the third, pneumatic controller is added; so, it makes the possibility to obtain at the same time, the consolidation and permeability tests in

four directions – downwards or upwards and inside or outside; for the “downwards” vertical permeability tests – $BP_{v1} > BP_{v2}$ and for the “upwards” vertical permeability tests – $BP_{v2} > BP_{v1}$ (Fig. 4); for the “inside” horizontal permeability tests $BP_{h1} > BP_{h2}$ and for the “outside” flow $BP_{h2} > BP_{h1}$ (Fig. 5).

- changes in the top horizontal valve localization; the site back pressure that provides the horizontal permeability tests has been fixed in the half way on the wall cell, as it is showed in Figure 5. That causes the better horizontal conditions, similar to *in situ* ones, than it is in the conventional Rowe cell, where the site back pressure is on the top of the cell wall.

The modified Rowe cell set allows to perform the consolidation and permeability tests at the same boundary conditions, because of added the air device controller (ADC) that can hold the load stress all the time, during the consolidation and permeability tests.

The modification made in the Rowe cell allows to perfectly transmit the water horizontally from the outside into inside the soil sample or other way. In the conventional solution, the water could first go not horizontally but vertically, even for horizontal permeability tests.

The modified Rowe cell set allows to perform the consolidation and permeability tests faster and more precisely with the *in situ* conditions.

To see the modifications advantages the comparable permeability tests should be performed. But, in this paper the main goal was to present the MRCS.

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Summary

The modified Rowe cell set for obtaining vertical and horizontal flow in soft organic soils. In the paper the modified Rowe

cell set (MRCS) is presented. Two main modifications were done: adding the third, pneumatic controller and changing the localization of the top horizontal valve. Thanks to that, the MRCS is adapted to measure, at the same time, the consolidation and permeability parameters and creates better, more similar to *in situ* ones, horizontal flow.

Streszczenie

Zmodyfikowany system z komorą Rowe'a do wyznaczania przepływu w kierunkach pionowym i poziomym w słabo- i średnio- i silnie organicznych gruntach. W pracy przedstawiono zmodyfikowany system z komorą Rowe'a (MRCS). Przeprowadzono dwie główne modyfikacje – dodano trzeci pneumatyczny kontroler oraz przełożono górny zawór do pomiaru przepływu poziomego. System został dzięki temu przystosowany do badań zarówno konsolidacji, jak i przepływu dla tych samych warunków brzegowych w tym samym czasie oraz do badania przepływów poziomych z możliwością większej precyzji zadawania poziomego drenażu do środka i na zewnątrz próbki gruntu.

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