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Determination of the coefficient of consolidation in soft organic soils using ACONS

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Abstract: *Determination of the coefficient of consolidation in soft organic soils using ACONS.* To determine the coefficient of consolidation using oedometer laboratory tests usually two common methods are used, Casagrande and Taylor. In the paper, the ACONS apparatus and ClispStudio program is characterized. The methodology and the test results of determination coefficient of consolidation in soft organic soils are presented. In the paper, the laboratory test results obtained from Automatic CONsolidation System are analyzed and the relationships between coefficient of consolidation, void ratio, and vertical stress are also presented.

Key words: coefficient of consolidation (c_v), soft organic soils, ACONS.

INTRODUCTION

To determinate the coefficient of consolidation using odeometer apparatus usually two common methods, leaning on Terzaghy theory, are used; Casagrande and Taylor (Head 1982). Therefore the exactly time of primary and secondary consolidation or degree of the consolidation should be known (Mesri and Godlewski 1977). Sometimes, it is impossible in soft organic soils.

The observation of deformation performance in field and laboratory investigations indicated that the consolidation process consist of two stages: primary settlement (immediate and consolidation), and secondary and tertiary settlement (creep) (Szymański and Sas 2001). The results of laboratory tests indicate that the parameters describing secondary compression depend on the effective stress level. Conventionally, the second phase of the settlements is regarded as being approximately linear in log time and is described as secondary settlements. In the long-term tests there is sometimes an upwards curvature of the log time-settlement curve in the secondary compression phase-creep. This phenomenon is called tertiary compression. Secondary and tertiary settlement is the result of creep of soil skeleton under the effective stress. It depends on rheological properties of soil and significantly depends on time (Sas et al. 2010).

The consolidation coefficient (c_v) is one of the mechanical parameters that should be obtained to estimate the value and the rate of strain of the soft organic subsoil under different loading (σ_v'). To determinate the coefficient of consolidation the value of the total settlement in time and the degree of consolidation should be known.

To obtain the consolidation coefficient in soft organic soils it is necessary to find the exact point of the end of consolidation settlement. Without knowing the time of 100% dissipation of water pore pressure it is difficult even in the automatic oedometer. In soft organic soils the time between consolidation settlement and tertiary settlement (creep) can be undetected. That's why it is difficult to find the t_{50} for U = 50% of consolidation for Casagrande method. The Taylor method is based on the changes of soil sample high in square time (Lambe and Whitman 1969; Mesri and Godlewski 1977; Head 1982).

MATERIALS AND METHODS

The ACONS is the shortcut of Automatic CONsolidation System. The system consist of: 1 – computer with ClispStudio program, 2 – miniscanner for registration, 3 – three automatic oedometers (display on photo below).

The main advantage of this system is the simplicity and automatization of the laboratory testing. On the every stage of the test it is possible to check and change the test conditions.

The set with ACONS apparatus and ClispStudio Program allows programming the swelling and consolidation tests. Different values of loading can be used with different conditions of start, stop and measurement criteria. The loading is pneumatic. With these three oedometers, three different samples in three diameters: 50, 75 and 100 mm, can be tested in the same time. The samples can be as well NNS, as NS.

In the ClispStudio program it is possible to set initial physical parameters and loading value. The program is able to read record and plot the results during the test (Fig. 1).

The program records the test results and the main characteristics can be analyzed during the test (Fig. 2).

The coefficient of consolidation in ACONS can be also calculated by the Casagrande or Taylor method, but the value of the coefficient of consolidation

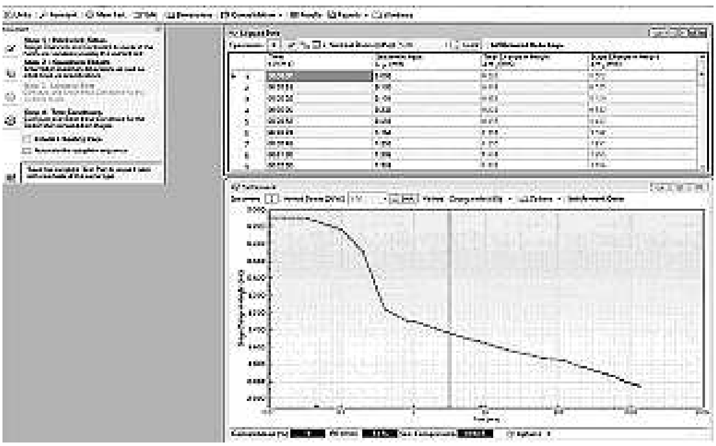

FIGURE 1. Sample of ACONS test recording made by ClispStudio

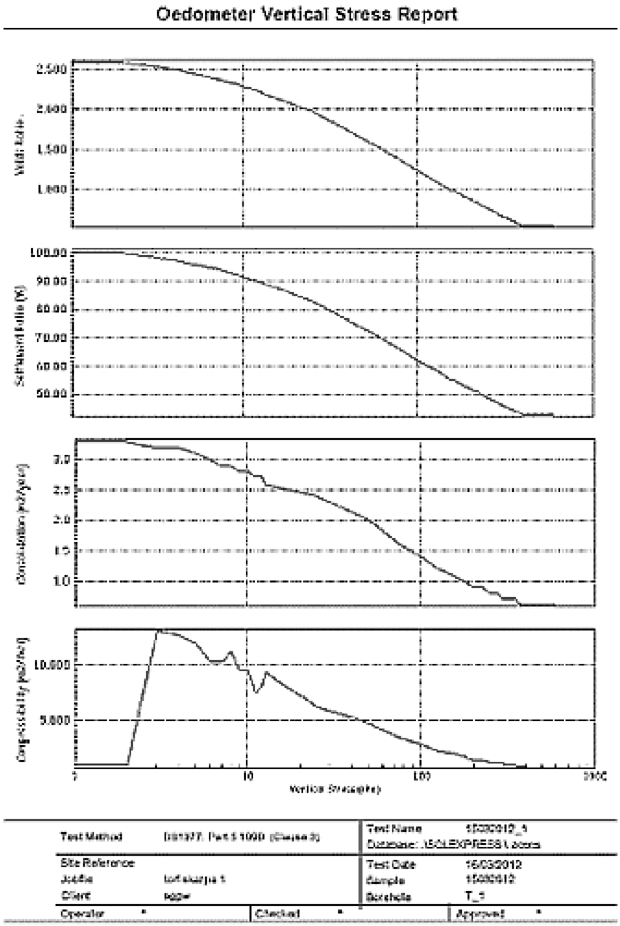

FIGURE 2. Sample of ACONS test results report made by ClispStudio

obtained from ClispStudio Program is not reliable. Only the curves plotted by the program can be used as the base to determine the coefficient. The curve plotted in the Casagrande method is in log time (Fig. 3) and the curve plotted by Taylor method is in square time (Fig. 4).

RESULT ADD DISCCUSSION

The test results of coefficient of consolidation

The laboratory tests are performed on soft organic NNS samples, taken from the Campus SGGW test site (Table 1).

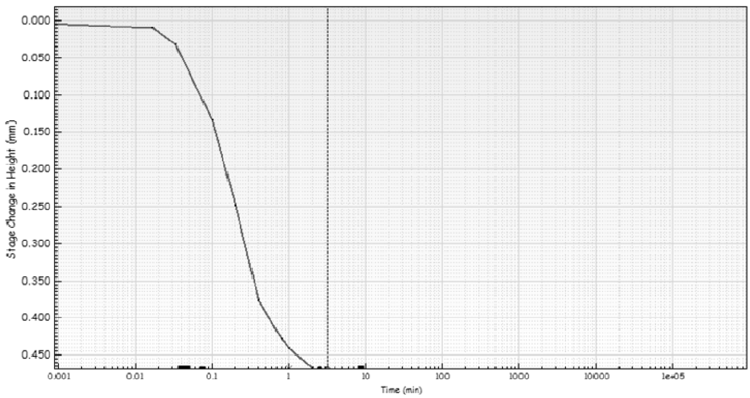

FIGURE 3. Sample of ACONS test results plot for Casagrande method

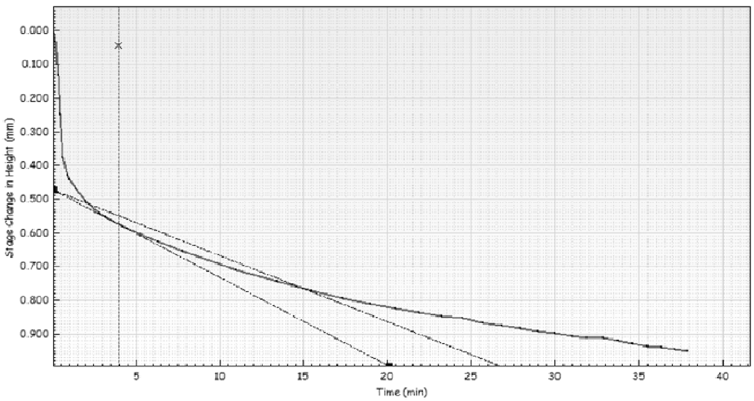

FIGURE 4. Sample of ACONS test results plot for Taylor method

TABLE 1. Physical properties of organic soils at tested site

Properties	Peat
Water content [%]	400
Density of solid particles ρ_s [t/m^3]	> 1.58
Bulk density ρ [t/m^3]	1.22
Plastic limit w_p [%]	136
Liquid limit w_L [%]	255
Plasticity index I_p [%]	118
Liquidity index I_L [%]	2.23
Organic matter content I_{OM} [%]	75
Degree of humification R [%]	65

The automatic consolidation system was used to obtain the stress-strain characteristics in soft organic soils in different range of loading, from 1 to 40 kPa. The oedometer tests consist of swelling and consolidation process.

The initial conditions are as follows:

- initial high [mm] – 20,
- initial diameter [mm] – 75,
- initial weight [gr] – 109.5,
- saturation [%] – 100,
- applied stress [kPa] – 1÷40.

The measured and calculated parameters are as follows:

- time [h:m:s],
- stage change in high [mm],
- void ratio *e* [–],
- coefficient of consolidation c_v [m^2/s].

The consolidation curve is presented in Figure 5. The value of the strain in time for vertical stress equal 10 kPa is presented in Figure 6.

To determinate the coefficient of consolidation in soft organic soils the Casagrande and Taylor method is used (Figs 7 and 8).

The comparisons between values of coefficient of consolidation determinated by the Casagrande and Taylor method are presented in Table 2.

The ACONS test results analysis

The soft organic soils are very compressible and anisotropic. Because of that, to complete the characterization of the strain parameters in soft organic soils, it is necessary to analyze the test results in the relationship between strain and void ratio in time (Fig. 9).

Analyzing the relationship between strain and void ratio in time it is possible

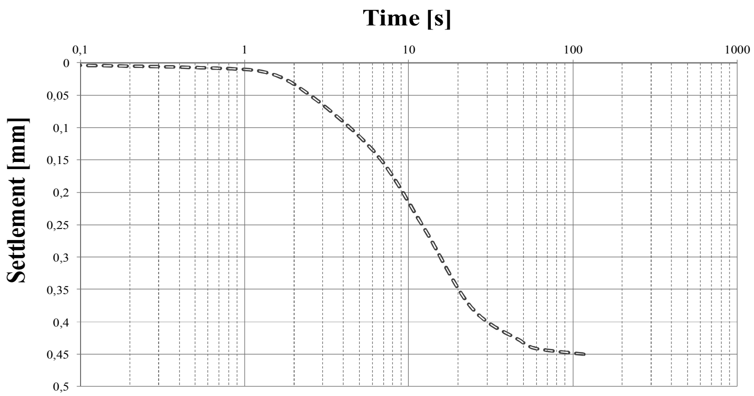

FIGURE 5. The consolidation curie for vertical stress equal 10 kPa

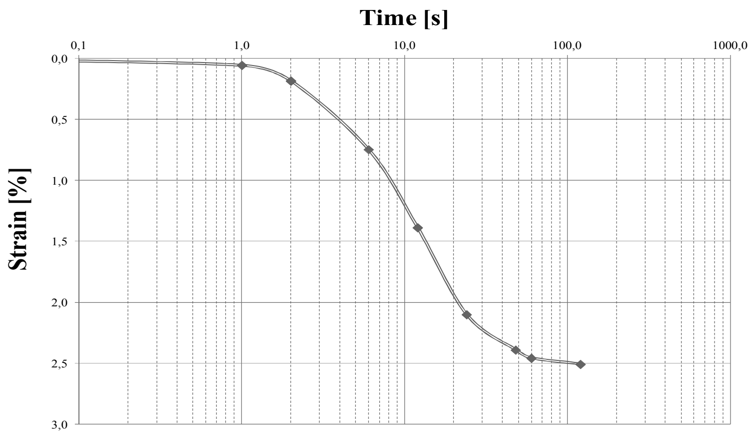

FIGURE 6. The value of the strain in time for vertical stress equal 10 kPa

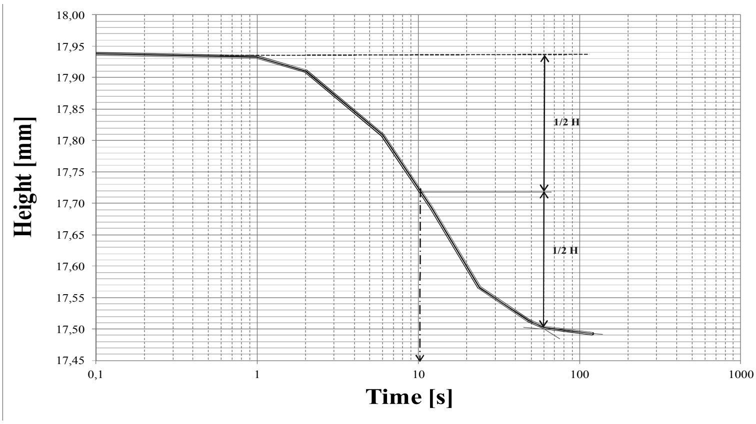

FIGURE 7. Determination of coefficient of consolidation by the Casagrande method for vertical stress equal 10 kPa

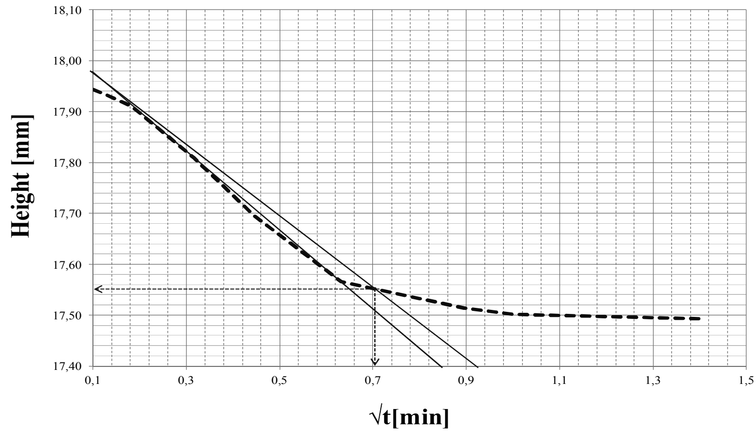

FIGURE 8. Determination of coefficient of consolidation by the Taylor method for vertical stress equal 10 kPa

TABLE 2. The comparison between the coefficient of consolidation determinate by the Casagrande and Taylor method

σ_v' [kPa]	e [–]	C_v [m^2/s] Casagrande method	C_v [m^2/s] Taylor method
5.0	6.05	$6.15 \cdot 10^{-6}$	$8.30 \cdot 10^{-6}$
10.0	5.60	$6.01 \cdot 10^{-6}$	$7.69 \cdot 10^{-6}$
15.0	5.35	$5.94 \cdot 10^{-6}$	$7.54 \cdot 10^{-6}$
20.0	5.10	$5.20 \cdot 10^{-6}$	$3.71 \cdot 10^{-6}$
25.0	4.95	$4.96 \cdot 10^{-6}$	$3.51 \cdot 10^{-6}$
30.0	4.80	$4.89 \cdot 10^{-6}$	$3.30 \cdot 10^{-6}$
35.0	4.60	$4.61 \cdot 10^{-6}$	$3.05 \cdot 10^{-6}$
40.0	4.40	$4.47 \cdot 10^{-6}$	$3.00 \cdot 10^{-6}$

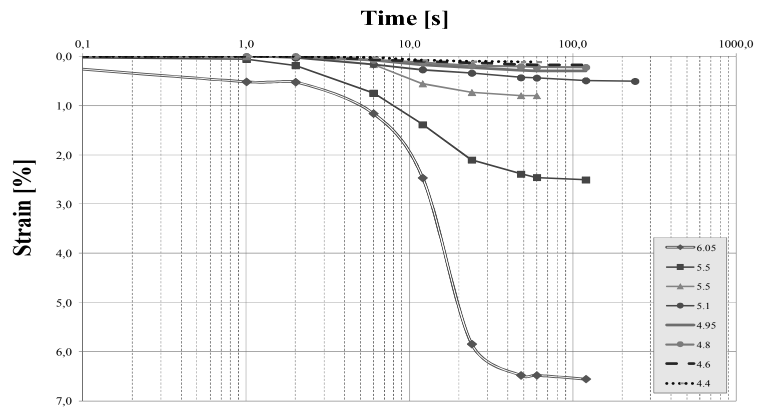

FIGURE 9. The value of strain in time for different void ratio

to propose a function that characterized this dependence (Fig. 10):

$$\varepsilon = 2.0 \times 10^{-6} \times e^{6.5} \times t^{0.25} \text{ [\%]} \qquad (1)$$

where: ε – strain [%], e – void ratio [–], t – time [s].

The Figure 11 point out the relationship between coefficient of consolidation in soft organic soils and void ratio.

And also, analyzing this relationship it is possible to propose a function that characterized dependence between coefficient of consolidation in soft organic soils in different vertical loading value and void ratio changes (Fig. 12):

$$c_v = 2.0 \times 0^{-6} \times e^{1.1} \times \sigma'^{-0.35} \text{ [m}^2\text{/s]} \qquad (2)$$

where:
c_v – vertical coefficient of consolidation [m^2/s],
e – void ratio [–],
σ' – vertical stress [kPa].

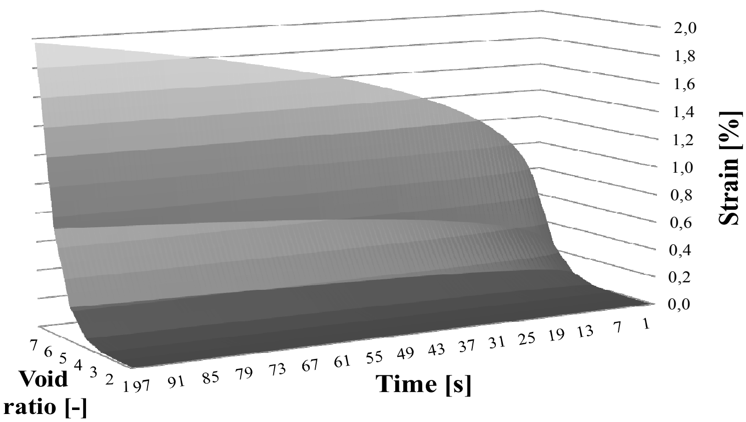

FIGURE 10. The relationship between strain and void ratio in time

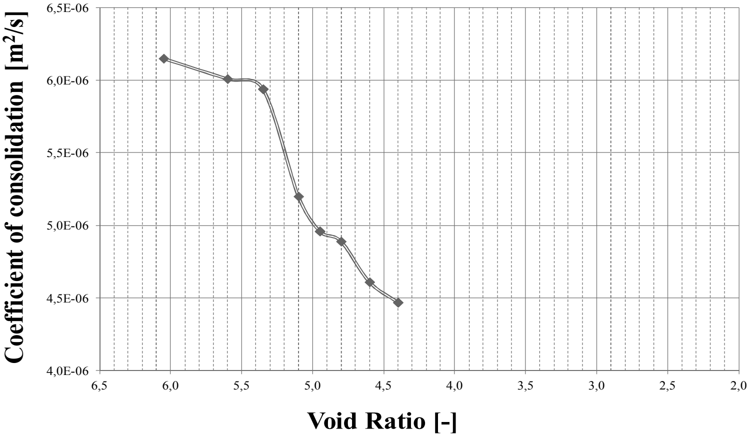

FIGURE 11. Change of coefficient of consolidation in void ratio

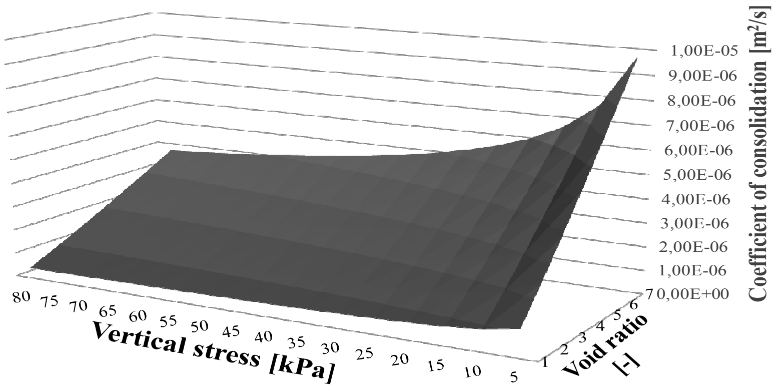

FIGURE 12. The relationship between coefficient of consolidation, void ratio and stress

CONCLUSIONS

The ACONS set allows to cut the time of the research that is a consequent's of pneumatic loading. The test type can be selected as swelling or consolidation with different border conditions. Three different tests on three different soils samples in three different dimensions can be tested at the same time. The ClispStudio program allows reading, writing and plotting the test results during the test.

To obtain coefficient of consolidation is soft organic soils it is important and extremely different to find the point of the end of consolidation stain and the beginning of tertiary stain that is very significant in this very compressibility and anisotropic soils. The Figure 13 point out the change of settlement in soft organic

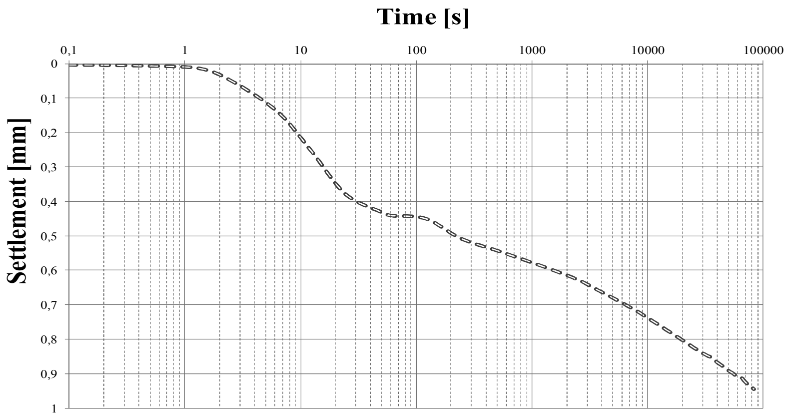

FIGURE 13. Change of settlement in long time for 10 kPa vertical stress

soil under 10 kPa stress, in long time period including creep process.

The coefficient of consolidation in soft organic soils should be obtained with the knowledge of the water pore pressure dissipation that gives the possibility of better identification of stress-stain characteristics.

The value of coefficient of consolidation in soft organic soils changes with the void ratio from $6.15 \cdot 10^{-6}$ [m^2/s] to $4.47 \cdot 10^{-6}$ [m^2/s] for Casagrande method that will be further considered. The comparison between values of the coefficient of consolidation obtained from the Casagrande method and Taylor method point out that the Casagrande method is more correct.

The dependence between coefficient of consolidation in soft organic soils in different vertical loading value and void ratio can be written as follows:

$$c_v = 2.0 \times 10^{-6} \times e^{1.1} \times \sigma'^{-0.35} \text{ [m}^2\text{/s]} \quad (3)$$

where:

c_v – vertical coefficient of consolidation [m^2/s],

e – void ratio [–],

σ' – vertical stress [kPa].

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Streszczenie: *Wyznaczanie współczynnika konsolidacji w słabonośnych gruntach organicznych z wykorzystaniem zestawu ACONS.* W celu wyznaczenia współczynnika konsolidacji w słabonośnych gruntach organicznych w laboratoryjnych badaniach edometrycznych zwykle stosowane są dwie podstawowe metody, Casagrande'a i Taylora. W artykule przedstawiono ACONS (zestaw automatycznych edometrów) wraz z oprogramowaniem ClispStudio. Podano charakterystykę zestawu i metodykę wyznaczania współczynnika konsolidacji w słabonośnych gruntach organicznych. W artykule zostały przedstawione i przeanalizowane wyniki badań uzyskane z ACONS. Zaproponowano także funkcję opisującą zależność współczynnika konsolidacji od wskaźnika porowatości i pionowego naprężenia.

Słowa kluczowe: współczynnik konsolidacji (c_v), słabonośne grunty organiczne, ACONS.

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