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Prediction of free field heave using C_w and C_H indices

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Abstract: *Prediction of free field heave using C_w and C_H indices.* In order to predict free heave in expansive silty clays two methods were applied: CLOD test and double-swelling methods. In both methods C_w and C_H indices are required respectively to determine the soil heave. The C_w index is determined as a slope of straight line of shrinkage curve obtained with a use of CLOD test. In case of double-swelling method two oedometer tests were carried out to determine C_H index: constant-volume and consolidation-swell oedometer tests. Comparison between heave values calculated using C_w and C_H indexes indicated slight differences.

Key words: expansive soil, free field heave, swelling

INTRODUCTION

A geotechnical design of buildings and road infrastructures in developed urban areas is generally regarded as a difficult engineering task, especially when highly expansive soils are distinguished in the ground. Already at the stage of designing the foundation of buildings the sensitivity of ground to changes in water content should be taken into account, particularly in the superficial zone, where water content fluctuations are great. Accurate diagnosis of soil heave, prediction of expansive properties of soil (like values of swelling index or swelling pressure) and

identification of geo-hazards are essential to design of the adequate measures to completely eliminate or remarkable reduce a potential of damaging the design building (Garbulewski 2000).

Researches invented several different procedures for heave prediction with a various degrees of accuracy, however the majority of previous methods only predict soil heave in terms of “low”, “medium”, “high” and “very high” (Van der Merwe 1964, Chen 1988). Recently, two methods for prediction of total heave were proposed: CLOD test method (Miller et al. 1995) and double-swelling method (Nelson et al. 2012). The CLOD method requires the soil samples to be covered by a liquid resin, which allows volume measurements to be conducted for various moisture content of the soil. In this method CLOD index C_w is determined as a slope of straight line of shrinkage curve (Fig. 1) using the following formula:

$$C_w = \frac{\Delta e}{\Delta w}$$

where:

Δe – change of void ratio [-]

Δw – change of moisture content [%].

FIGURE 1. Shrinkage curve in terms of void ratio and water content for determining the CLOD index

Heave index (C_H) can be determined from consolidation-swell test data along with data from constant-volume tests (Fig. 2) as a slope of straight line connecting the point defined by the percent

swell in a consolidation-swell test, point A, and point corresponding to the constant volume swell pressure, point C, (Nelson et al. 2012).

The C_H index can be determined using following formula:

$$C_H = \frac{\%S_A}{\log \left[\frac{\sigma'_{cv}}{(\sigma'_i)_A} \right]}$$

where:

$\%S_A$ – percent swell at point A,
 σ'_{cv} – constant-volume swelling pressure,
 $(\sigma'_i)_A$ – inundation stress at point A.

FIGURE 2. Hypothetical oedometer test results – heave index determination (Nelson et al. 2012)

This paper contains comparison between free field heave values obtain using the above mentioned two methods. The calculation of heave values was performed for silty clay.

MATERIAL AND METHODS

Material

Samples were prepared adding 15% of bentonite to kaolinite in order to make a soil swell. Kaolinite is typically non-expansive clay while bentonite contains more than 80% of highly expansive minerals (mainly montmorillonite) (Grabowska-Olszewska 1998). Grain size distribution of tested soil and their basic physical properties are presented at Figure 3 and Table 2. According to the standard ISO 14688-1 classification soil should be classified to silty clay (siCl).

CLOD test method

To estimate a shrinkage curve of tested soil CLOD test method was applied according to the procedure given in 1985 by Hamberg in Colorado State University. The test procedure consisted in the following steps (Perko, Thompson, Nelson 2000):

- take a soil sample with any shape (CLOD) and determination of its initial weight (W_1);
- wrapping a soil clod by thin thread and determination of its weight (W_2);
- cover soil sample by liquid resin – DOW Saran F310 (Fig. 4) dissolved

FIGURE 3. Grain size distribution of tested soil

TABLE 2. Basic physical properties of tested soil

G_s	w_L	w_p	w_s	I_p	ρ_d	e_o	w_o
—	%	%	%	%	Mg/m ³	—	%
2.6	90	26.5	16.8	63.5	1.52	0.71	23.6

FIGURE 4. Covering soil sample by liquid resin

in acetone in relation 1 g of Saran resin to 7 g of acetone. Soil sample was covered with resin three times. First time it was dried 5 min, second time 8 min and third time 55 min. After last drying, the soil sample covered with resin was weighed (W_3) – Figure 5;

FIGURE 5. Clods of tested soil during drying

- resin is impermeable to water for a short period of contact, which allows determining the volume of soil samples from the Archimedes law. Soil sample was immersed in water and determined the weight of water displaced by the sample (W_4), temperature of water was measured too;

- resin is permeable to water vapor present in the sample which allows for sample drying. For selected periods of drying the weights of sample (W_5) and the weight of water displaced (W_6) are determined;
- when drying is completed, soil clod is dried for 48 h at 105°C and one determines its weight (W_7) and weight of water displaced (W_8). By drying in an oven the weight of the resin may drop by 15%.

The test results are presented as a relationship between the change of soil volume to change of water content (Fig. 1).

Double-swelling method

In this method in order to define a corrected swelling pressure (Fig. 6) constant-volume oedometer test should be performed. Moreover, a consolidation – swell test should be also undertaken. Results of both tests are required to determine heave index (Fig. 2).

FIGURE 6. Determination of corrected swelling pressure [P'_s (σ'_{cv})] from oedometer test (Fredlund and Rahardjo 1993)

DETERMINATION OF HEAVE VALUES

General assumptions

For determination of heave values the following assumptions were made:

- thickness of silty clay layer equal 0.3 m,
- final pore water pressure equal 0 kPa,
- initial void ratio $e_o = 0.71$.

CLOD test method

Total free field heave (ρ_{CLOD}) was estimated using the following formula:

$$\rho_{\text{CLOD}} = \frac{C_w \cdot \Delta w}{1 + e_o} \cdot z_i$$

where:

C_w – CLOD index [-]

Δw – change of moisture content [%],

e_o – initial void ratio [-],

z_i – thickness of soil layer [m].

The C_w index, estimated as an average value from five soil samples (Fig. 7), was equal 0.0143. It was observed that generally the initial water content near the surface did not fall much below the shrinkage limit. Also, the maximum water content under the simulated floor slab did not significantly exceed the plastic limit, so change of water content (Δw) at the surface is as follows:

$$\Delta w = PL - SL = 26.5 - 16.8 = 9.7\%$$

Therefore, the value of free field heave is as follows:

$$\rho_{\text{CLOD}} = \frac{0.0143 \cdot 9.7}{1.71} \cdot 0.3 = 24.3 \text{ mm}$$

FIGURE 7. Shrinkage curve in terms of void ratio and water content for determining the CLOD index

Double-swelling method (DSM)

Total free field heave (ρ_{DSM}) value was determined using following formula:

$$\rho_{\text{DSM}} = C_H \cdot \Delta z_i \cdot \log \left[\frac{\sigma'_{cv}}{(\sigma'_{vo})_z} \right]$$

where:

C_H – heave index [-],

Δz_i – thickness of soil layer [m],

$(\sigma'_{vo})_z$ – stress at the midpoint of the layer at depth z [kPa],

σ'_{cv} – constant-volume swelling pressure.

With a use of constant-volume oedometer test (Fig. 8), the corrected swelling pressure was determined as a 320 kPa. Index of C_H obtained from consolidation-swell and constant-volume oedometer test (Fig. 9) was equal 0.041.

FIGURE 9. Heave index (C_H) estimation using consolidation-swell and constant-volume oedometer test

The total free field heave for layer of 0.3-meter thick is as follows:

$$\rho_{\text{DSM}} = 0.041 \cdot 0.3 \cdot \log \left[\frac{320}{2.24} \right] = 26.5 \text{ mm}$$

FIGURE 8. Estimation of a corrected swelling pressure using constant-volume oedometer test

FINAL REMARKS AND CONCLUSION

Swelling of fine-grained soil is the cause of failure of many buildings, especially light ones, such as street paving, low building foundations etc. Consequently, this is extremely important to predict a total heave of soil in correct way. There are few methods to estimate the total heave. Some of them only briefly indicate the swelling potential of soil however, nowadays more precise methods have been proposed (Fredlund, Rahardjo 1991).

In this paper two methods recently suggested for determination of total soil heave were compared: CLOD and DSM tests. CLOD test is a simple method to develop a shrinkage curve and estimate total heave of soil layer. The DSM method is more sophisticated and it needs two types of tests: the constant-volume and consolidation-swell oedometer test. It should be pointed out that these two methods give significantly different values of total heave. From CLOD test, which is simpler and less time-consuming method, the free field heave is lower (8.1%) in comparison with the DSM method (8.8%). The results are interesting and encouraging. Further research on this issue should contain tests on natural expansive soils.

REFERENCES

- CHEN F.H. 1988: Foundations on expansive soils. Elsevier.
- Department of the Army USA, Technical Manual TM 5-818-7, Foundations in expansive soils, 1 September 1983.
- FREDLUND D.G., RAHARDJO H. 1991: Stress state variable approach to the prediction of heave. International Workshop on Clay Swelling and Expansive Soils, Cornell University, Ithaca, New York, U.S.A. 12-16 August 1991.
- FREDLUND D.G., RAHARDJO H. 1993: Soil mechanics for unsaturated soils. Canada.
- GARBULEWSKI K. 2000: Ocena ekspansywności gruntów na podstawie charakterystyk skurczalności [Evaluation of soil expansivity on the basis of the shrinkage characteristics]. *Inżynieria Morska i Geotechnika* 3/200, 136–140.
- GRABOWSKA-OLSZEWSKA (red.) 1998: Geologia stosowana. Właściwości gruntów nienasyconych. Applied geology. Properties of unsaturated soil. PWN, Warszawa.
- MILLER D.J., DURKEE D.B., CHAO K.C., NELSON J.D. 1995: Simplified heave prediction for expansive soils. Proceedings 1st International Conference "Unsaturated Soils", Paris, E.E. Alonso, P. Delage (Eds), Vol. 2, 891–898.
- NELSON J.D., MILLER D.J. 1992: Expansive soils. Problems and practice in foundation and pavement engineering. Department of Civil Engineering, Colorado State University.
- PERKO H.A., THOMPSON R.W. 2000: Nelson J.D. Suction Compression index based on CLOD Test Results. *Advances in Unsaturated Geotechnics*, doi: 10.1061/40510(287)27.
- Van der MERWE D.H. 1964: The prediction of heave from the plasticity index and percentage fraction of soils. *Civil Eng. in South Africa* 6, 6, 103–107.

Streszczenie: Określenie całkowitego podniesienia gruntu przy użyciu indeksów C_w i C_H . W celu określenia całkowitego podniesienia gruntu wykorzystano dwie metody: metodę CLOD i metodę wykorzystującą podwójne badanie edometryczne. W metodach tych należy wyznaczyć kolejno indeksy C_w i C_H w celu określenia całkowitego podniesienia gruntu. Indeks C_w jest określany jako nachylenie prostej części krzywej skurczalności, wyznaczonej metodą CLOD. W metodzie wykorzystującej badania edometryczne niezbędne jest przeprowadzenie badania

stałej objętości gruntu i badania stopniowego obciążania spęczniałej próbki w celu wyznaczenia indeksu C_H . Wielkości całkowitego podniesienia gruntu określone obiema metodami wykazują niewielkie różnice.

Słowa kluczowe: grunty ekspansywne, podniesienie, pęcznienie

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