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Experimental Tests of the Deformation and Consolidation Properties of the Cohesive Soils and Their Use in the Geotechnical Calculations

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Abstract: The paper deals with experimental determination of deformations and consolidation characteristics (modules of deformation and elasticity, coefficient of consolidation) of cohesive soils in the laboratory conditions. Deformation characteristics in the oedometer device are analyzed in detail (one-dimensional state of strain is assumed). Determination of representative deformations and consolidation characteristics of cohesive soils are necessary for design of the geotechnical structures from the 2nd group of limit states (serviceability) point of view.

Keywords: Experimental, Oedometrical Test, Oedometrical Module of Deformation, Consolidation, Consolidation Coefficient

1. Introduction

For design and assessment of the foundation structures according to the 2[nd] group of the limit states (limit state of serviceability) the technical standards [1] and [3] require the calculation of the final and non-uniform settlement. In accordance with STN 73 1001 [3] the final settlement "s" of foundation can be calculated by relation:

$$s = \sum_{i=1}^{n} \frac{\sigma_{z,i} - m_i \cdot \sigma_{or,i}}{E_{oed,i}} \cdot h_i \tag{1}$$

where: $\sigma_{z,i}$ is vertical stress from the additional structure load; m_i – correction coefficient of additional structure load (so–called coefficient of the structural strength); $\sigma_{or,i}$ – geostatic stress; h_i – thickness of i^{th} soil layer; $E_{oed,i}$ – oedometrical deformation modulus of soil in the foundation subsoil.

Most significant influence on the size of calculated final settlement has the oedometrical deformation modulus"E_{oed}". This modulus is determined assuming the

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one-dimensional state of deformation (Fig. 1). From this assumption it is obvious, that compression of the soil sample is non zero in the vertical direction ($\varepsilon_z \neq 0$) and deformations in horizontal direction are zero ($\varepsilon_x = \varepsilon_y = 0$). Relative strain in vertical direction according to this formula is calculated: $\varepsilon_{zi} = \Delta h_i / h_o$. Relation between deformation soil modulus "E_{def}" (determined on the 3D state of strain) and oedometrical deformation modulus "E_{oed}" is represented by well-known formula [3]

$$E_{oed} = \frac{1}{\beta} \cdot E_{def} \tag{2}$$

where β is the coefficient calculated by expression:

$$\beta = 1 - \frac{2\nu^2}{1-\nu} \tag{3}$$

where ν is Poisson's ratio.

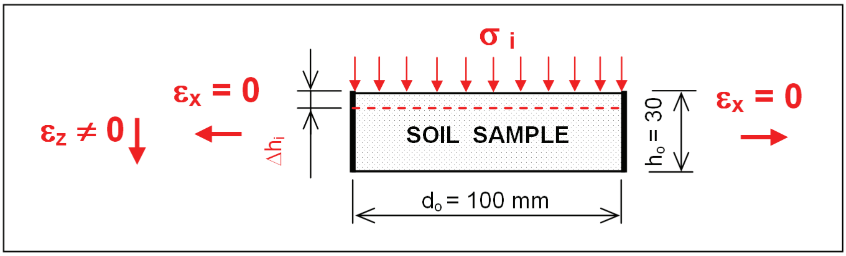

Fig. 1. Boundary conditions of the oedometrical test.

Determination of oedometrical modulus especially for cohesive soils is rather difficult (clay and loam). For the cohesive soils it is important to determine the rheological properties, too. Methodology and boundary conditions for determination of E_{oed} for cohesive soils are specified in STN 72 1027 [4]. For determination of the oedometrical deformation modulus "E_{oed}" in geotechnical calculations it is important to take into account especially the following factors:

- genesis of soils and their grain composition,
- original geostatic stress (depth of taking of soil samples),
- geological composition and foliation of subsoil,
- change of stress state in subsoil by influence of additional load by structure.

In the next part the boundary conditions and geotechnical interpretation of oedometrical test results for soils in foundation natural subsoil will be analysed in detail.

2. Boundary conditions of the oedometrical test

Boundary conditions and interpretation of compressibility laboratory test results (oedometrical test) of soils are presented in STN 72 1027 [4]. By this test we have set oedometrical deformation modulus (E_{oed}), oedometrical elasticity modulus ($E_{oed,el}$) and consolidation coefficient (c_v) of cohesive (clay, loam) and sandy soils. For purposes of the settlement calculation Eq. (1) it is important to use undisturbed test sample type "N" (i.e. soil sample obtained from foundation subsoil). During the test it is necessary to make reconsolidation under stress "σ_r". The value of "σ_r" is equal to vertical effective stress in the place (depth) where the sample was taken. Time of reconsolidation cycle "t_c" depends on the type (granularity) of soils (sandy soils - t_c=2,0 hours; loam - t_c=6,0 hours; clay - t_c=24,0 hours).

After the reconsolidation process, the analyzed sample is gradually loaded by several levels of normal stresses. In the case of test type A and B the acting load is constant during one loading cycle (most frequently used type of tests). In the case of test type C the acting load is continually increased. In the case of test type A only finite deformation is monitored. Process of test type B is similar like test type A, however, we note in detail the time development of deformation during the load cycle. From the final value of deformation we determine oedometrical deformation modulus "E_{oed}" and from the time development of deformation influence the consolidation coefficient "c_v". Time "t_c" load action during particular loading cycle is the same like in reconsolidation process. The ratio of the load intensity of the next and previous load cycles σ_i/σ_{i-1} is 1,5 to 2,5 (where "σ_i" is vertical normal loading). The load "σ_i" must be chosen with respect to the designed change in the state of stress in the subsoil caused by the additional load from the structure.

3. Evaluation of the deformation characteristics

Basic characteristic obtained from the oedometrical test is the oedometrical deformation modulus "E_{oed}" and the oedometrical elasticity modulus "$E_{oed,el}$". Oedometrical deformation modulus is calculated from additional loading process for different σ_i and oedometrical elasticity modulus is calculated from unloading process. From the graphic representation of the dependence between vertical normal stress acting on the sample (σ_i) and vertical strain (ε_i) we get compressibility curve (called compression curve). The compressibility curve for clay soil (classification according to STN 73 1001: clay with low plasticity) is presented in Fig. 2.

Table 1 shows calculated deformation characteristics for different loading steps (σ_i).

Oedometrical deformation modules ($E_{oed,i}$) were calculated according to formula

$$E_{oed,i} = \frac{\sigma_i - \sigma_{i-1}}{\varepsilon_i - \varepsilon_{i-1}} = \frac{\Delta\sigma_i}{\Delta\varepsilon_i} \tag{4}$$

Oedometrical elasticity modulus ($E_{oed,el}$) is calculated by the equation (4) while only a part of elasticity strain ($\Delta\varepsilon_{i,\,el}$) is substituted.

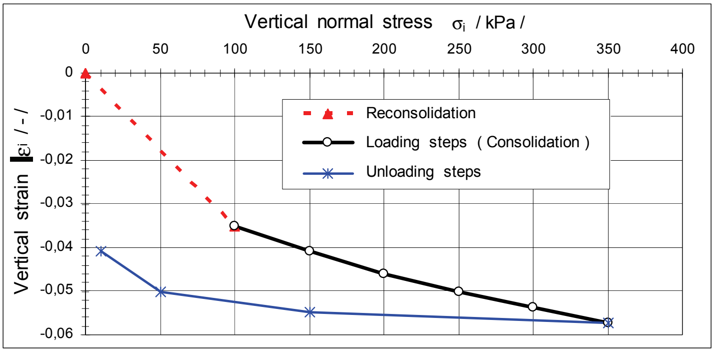

Fig. 2. Evaluation of compressibility curve with loading and unloading steps [5].

Table 1. Calculated values of deformation and rheological characteristics of the different load levels of the clay soil sample (for clay with low plasticity) [5]

Loading step (σ_i) / kPa/	Oedometrical deformation modulus $E_{oed,i}$ /MPa/	Oedometrical elasticity modulus $E_{oed,eli}$ /MPa/	Consolidation coefficient $c_{v,i}$ / $m^2.s^{-1}$/	Note
100 - 150	8,43	-	-	Additional loading of sample
150 – 200	9,8	-	1,83 . 10^{-8}	
200 – 250	11,9	-	-	
250 – 300	14,42	-	-	
300 – 350	14,02	-	3,93 . 10^{-9}	
50 – 350	11,71	-	-	
350 – 150	-	84,51	-	Unloading of sample
350 - 50	-	41,28	-	

4. Evaluation of the consolidation (rheological) characteristics

From the time development of the soil sample compression the consolidation (rheological) characteristic, i.e. consolidation coefficient "c_v" is evaluated. In [4] two following methods of calculation are presented:

a) Logarithmical (Casagrande´s) method for calculation of “c_v“ according to expression:

$$c_v = \frac{0{,}049.h_{50}{}^2}{t_{50}} \tag{5}$$

b) “Root” (Taylor´s) method for calculation of “c_v“ according to expression:

$$c_v = \frac{0{,}212.h_{90}{}^2}{t_{90}} \tag{6}$$

where: h_{50} (h_{90}) is a height of the test sample in 50% (90%) of primary consolidation; t_{50} (t_{90}) is a time needed to obtain the 50% (90%) degree of primary consolidation.

These methods are based on assumptions of the Terzaghi´s one-dimensional theory of consolidation [6]. Example of graphical evaluation of the time-depended compression of soil samples for the logarithmic method is shown in Fig. 3. Calculated values of "c_v" according to the logarithmical method are given in Tab. 1.

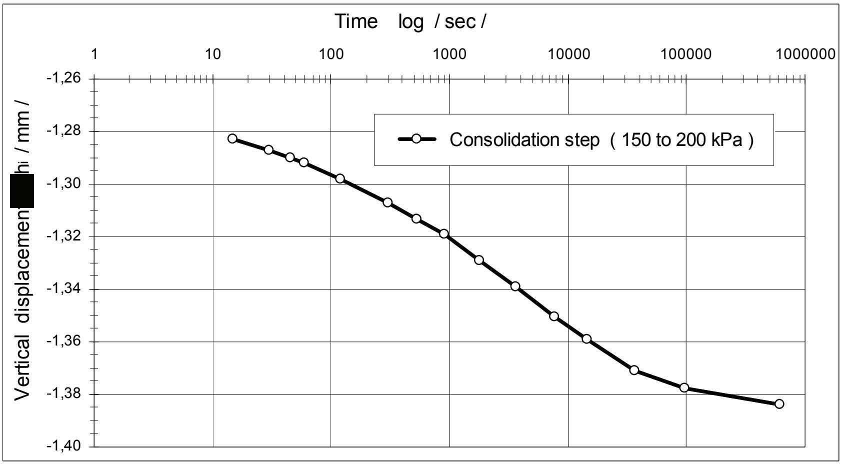

Fig. 3. Evaluation of time course of the sample compression by logarithmical method for loading step from 150 kPa to 200 kPa [5].

5. Conclusions

Calculation value of the final and non-uniform building structure settlement is necessary for determination of deformation properties of soil. Period of the final settlement of structure depends on consolidation (rheological) characteristics of soil. Correct assessment of the deformation and rheological soil properties has significant influence on design of foundation and its examination of the 2nd limit state (serviceability limit state). Due to this fact it is important to give attention to their correct evaluation.

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References

[1] EN 1997-1:2004: *EUROCODE 7 - Geotechnical design – Part 1: General rules* (in Slovak).

[2] EN 1997-2:2004: *EUROCODE 7 - Geotechnical design – Part 2: Ground investigation and testing* (in Slovak).

[3] STN 73 1001: *Foundation of structures* (in Slovak).

[4] STN 72 1027: *Laboratory determination of soil compressibility in the oedometer apparatus* (in Slovak).

[5] Kuzma J. et. al., *Geotechnical investigation. Reconstruction of JE V-1 in Jaslovské Bohunice, TVD 1st and 2nd Block* (in Slovak) (SvF STU, Bratislava, 2000), 126 pp.

[6] Jesenák J., *Soil mechanics* (in Slovak) (STU, Bratislava, 1994). ISBN 80-227-0642-6.