INTERNATIONAL SOCIETY FOR
SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering
© 2005–2006 Millpress Science Publishers/IOS Press.
Published with Open Access under the Creative Commons BY-NC Licence by IOS Press.
doi:10.3233/978-1-61499-656-9-603

Geotechnical characteristics determining consolidation in organic soils

Les caracteristiques géotechniques décrivant les process de consolidation des sols organiques

A. Szymanski, Z. Lechowicz, A. Drozdz & W. Sas
Department of Geotechnical Engineering, Warsaw Agricultural University, Poland

ABSTRACT
The paper presents the results of field and laboratory investigations carried out on two test embankments located on soft soils in north-western Poland. Comprehensive investigations including observations of test embankments and laboratory testing have been conducted in order to study the behaviour of the consolidation process in soft subsoil. This paper presents the analysis of factors determining the assessment of the deformation process of soft subsoil. The analysis was focused on determining non-linear deformation-stress characteristics used for modelling the deformation of soft subsoil under the earth structure. Deformation characteristics obtained in laboratory tests were compared with field measurements, which included vertical and horizontal displacements, as well as pore pressure dissipation. Based on analysis of field observations and laboratory tests results, the characteristics determining the consolidation process were elaborated.

RÉSUMÉ
L' article présente les résultats des essais in situ et au laboratoire réalisés sur les périmètres expérimentaux situés dans la région nord - est de Pologne. Les essais concernaient les mesures des variations des déplacements de la fondation, chargée par des remblais experimentaux. Des essais au laboratoire de tourbe et de gyttja ont également été réalisés afin de déterminer le procès de consolidation des sols faibles. Les résultats obtenus lors des essais au laboratoire ont été comparés aux essais in situ. Les relations empiriques décrivant les procès de deformation des fondations chargées ont été définies.

1 INTRODUCTION

Construction of embankments on soft organic soils poses specific problems. The most obvious ones are large deformations that may occur during and after the construction period, both vertically and horizontally. The settlements often appear quickly but may also continue for very long time periods due to creep (Larsson, 1986). The low shear strength often causes stability problems, and consequently the load sometimes has to be placed in stages or, alternatively, the soil must be improved through prior treatment. The selection of a suitable construction schedule involves estimation of the final settlement, as well as prediction of the subsoil deformation course and pore pressure dissipation. Data on the current state of elevation of each subsoil layer and the effective stress distribution allow determining the shear strength increase and stability evaluation (Hartlen & Wolski, 1996).

Organic soils, which according to their definition contain a varying proportion of organic matter, include peat (remains of dead vegetation in various stages of decomposition), gyttja (plant and animal remains deposited in lakes), and organic silts and clays. These soil types differ greatly with respect to engineering properties. Organic clays and silts behave rather similarly to inorganic cohesive soils, whereas peats, particularly those that are fibrous with a small degree of humification, have extraordinary properties. Several years of observations carried out on test embankments built on amorphous peat and calcareous soil have provided some information concerning the performance of the consolidation process in organic soils (Wolski et al.; 1988, Szymanski, 1994; Lechowicz, 1994).

The paper consists of two parts:

- The first part is dedicated to the general behaviour of organic soil under loading as well as analysis of subsoil deformation and consolidation under embankments;
- The second part is devoted to the analysis of deformation parameters used in prediction of consolidation.

In this paper the results of oedometer and triaxial tests conducted on overconsolidated and normally consolidated specimens of peat and calcareous soil are presented. The results of the laboratory tests and field measurements were used to evaluate the deformation characteristics.

2 DESCRIPTION OF THE TEST AREA

The test site is located in north-western Poland in the Noteć River valley where in the project of flood control, levees and dykes construction was conducted. In the cooperation between the Swedish Geotechnical Institute and the Department of Geotechnics, two test embankments have been constructed in stages at the Antoniny site (Lechowicz, 1992; Szymanski, 1991).

The soft subsoil consists mainly of peat and calcareous soil with a very high content of calcium carbonate (Fig. 1).

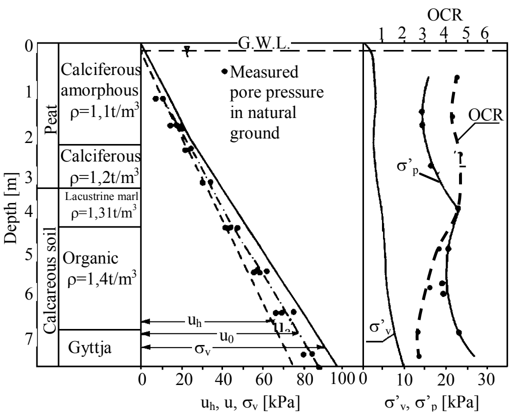

Figure 1. Geotechnical conditions in organic subsoil.

The results of oedometer tests indicate that the organic soils are overconsolidated with the preconsolidation pressure σ'_p around 15 kPa for peat and around 22 kPa for calcareous soil. During the construction, in the first stage the effective vertical stress still remained below the initial preconsolidation pressure but in the second and third stage the effective vertical stresses were higher than the initial preconsolidation pressure.

3 FIELD INVESTIGATIONS

At the Antoniny site two embankments were built in stages to reach the final height of 3.9 m. The embankment construction had to be divided into three stages. Geodrains in a square pattern with a 1.2 m spacing were installed under one of embankment.

The subsoil behaviour was monitored by means of piezometers, various types of settlement gauges, and inclinometers that allowed measurements of vertical and horizontal displacements and pore pressures. The measured deformation and pore pressure response at both test embankments provided the basis for estimating the influence of geodrains on organic subsoil deformation. The magnitude of subsoil deformation at the end of the first and second stages is presented in Figure 2.

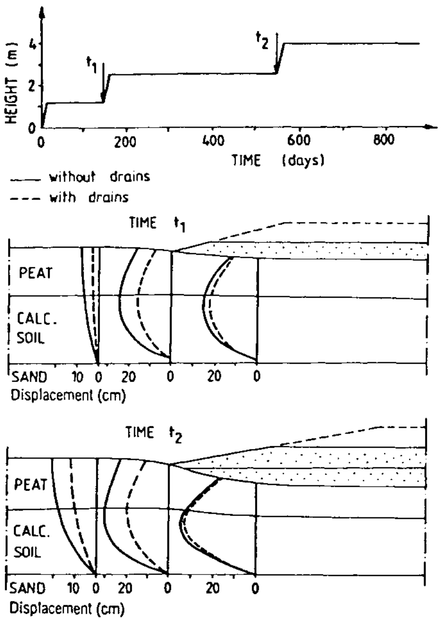

Figure 2. Vertical and horizontal displacements under embankment slopes.

During observations of the behaviour of embankments at the Antoniny site, an additional effect of vertical drains installed in highly compressible soil was detected. When the subsoil of the embankment with vertical drains was compared with that without drains it was found that the performance of vertical drains changed the pattern of horizontal displacements, i.e., they were smaller and their distribution was more confined. This decrease of horizontal displacement was associated with an increase of undrained shear strength (Lechowicz et al., 1987; Koda et al., 1993).

To explain the background of this effect, which can be termed confining, some observation data will be analysed. The initial pore pressure conditions are characterised by a small artesian pressure in the sand layer underlying the compressible organic formation. After loading, the dissipation of the excess pore pressure was more rapid in the part of the subsoil with Geodrains. The pore pressures, measured almost 1 year after loading with the second stage of the embankment, are significantly lower within the part with Geodrains than outside. In other words, in the subsoil of the embankment with Geodrains, the pore pressure was lower under the embankment than in the confining zone. The same pattern of pore pressure distribution was obtained during observation after the first and third stages of loading.

The created seepage pressure, of the opposite direction to the horizontal stresses entailed by loading, had to diminish the horizontal displacements. Those measured under the base of the embankment slope with Geodrains were 30-50% lower than those without Geodrains. Moreover, under the embankment with Geodrains the horizontal displacements were confined to a narrower zone than under the embankment without Geodrains.

4 LABORATORY TESTS RESULTS

Laboratory tests presented in this paper were performed on peat and calcareous soil samples taken from organic subsoil at the end of second construction stage. At that time peat and calcareous soil were normally consolidated under maximum effective vertical stress about 40 kPa for peat and 35 kPa for calcareous soil.

Triaxial tests were performed to evaluate the deformation and strength characteristics for overconsolidated and normally consolidated stress states, which are required for estimating the displacement of organics subsoil. In order to determine the deformation parameters for fully drained and undrained conditions, triaxial tests were carried out.

The relationship between the Young modulus E for fully drained conditions versus effective stress components σ'_1 and σ'_3 can be shown as follows

$$E = \alpha_0 \cdot \sigma_1'^{\alpha_1} \cdot \sigma_3'^{\alpha_2} \qquad (1)$$

where α_0, α_1, α_2 = empirical coefficients.

For organic soils from the Antoniny site the following values of empirical coefficients to Eq. 1 for peat are $\alpha_0 = 2770$, $\alpha_1 = -1.95$, $\alpha_2 = 2.16$ and for calcareous soil $\alpha_0 = 947$, $\alpha_1 = -1.12$, $\alpha_2 = 1.53$ (Fig. 3 & 4).

The relationship between the Young modulus E_u for undrained conditions versus deviatory stress q and consolidation stress σ_c can be shown as follows

$$E_u = \beta_0 \cdot q^{\beta_1} \cdot \sigma_c^{\beta_2} \qquad (2)$$

where β_0, β_1, β_2 = empirical coefficients.

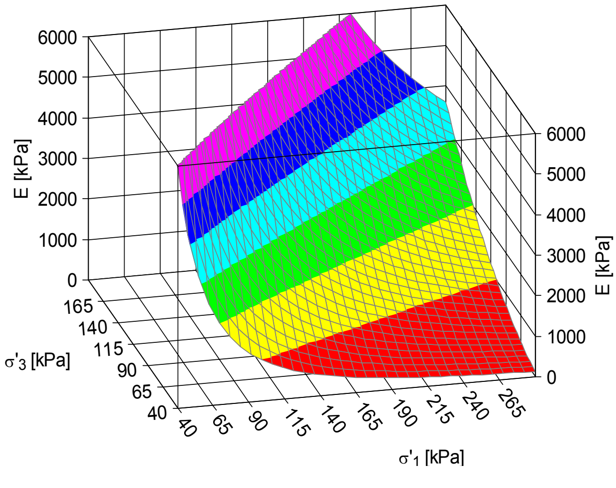

Figure 3. Relationship between drained modulus E versus stress components σ'_1 and σ'_3 for peat.

The analysis of test results indicates that the obtained values of empirical coefficients to Eq. 2 for peat are $\beta_0 = 17.5$, $\beta_1 = -0.86$, $\beta_2 = 1.70$ and for calcareous soil $\beta_0 = 3.51$, $\beta_1 = -0.78$, $\beta_2 = 2.11$ (Fig. 5 & 6).

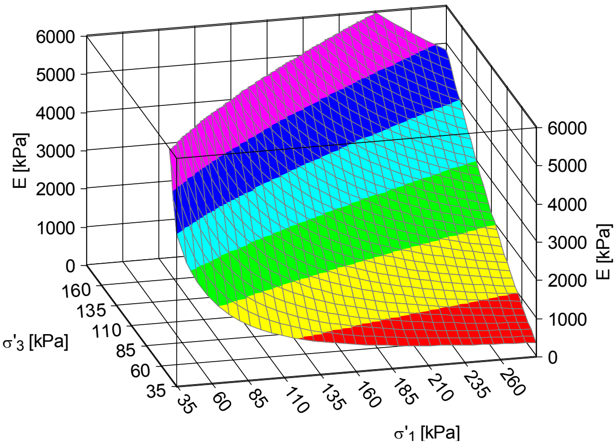

Figure 4. Relationship between drained modulus E versus stress components σ'_1 and σ'_3 for calcareous soil.

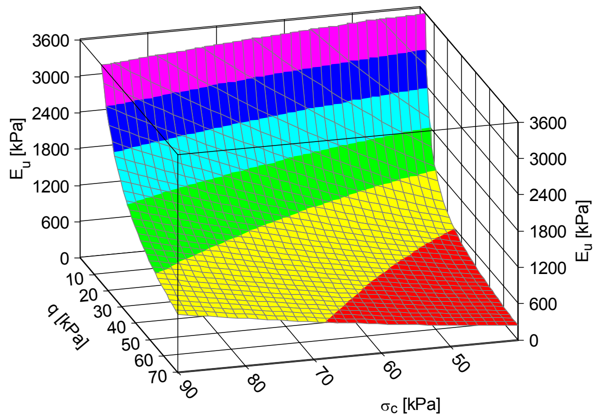

Figure 5. Relationship between undrained modulus E_u versus deviatory stress q and consolidation stress σ_c for peat.

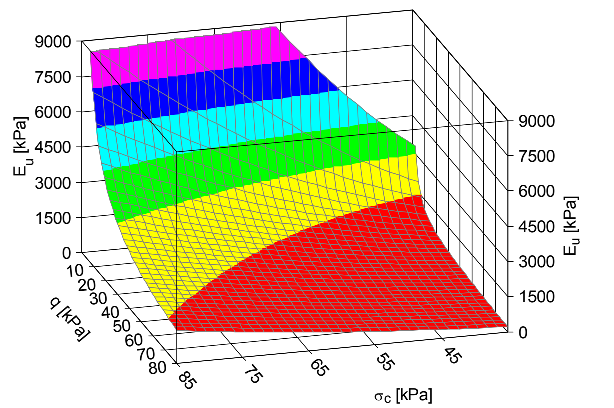

Figure 6. Relationship between undrained modulus E_u versus deviatory stress q and consolidation stress σ_c for calcareous soil.

In organic soils considerable secondary deformations depending on time occur (Szymanski & Sas 2001). Creep tests were made in standard triaxial cells for peat and calcareous soil. For each soil two series of tests were performed, one on unconsolidated samples and second on samples consolidated under the effective stress of about 35 kPa. Test series were done under different deviatory stresses. Creep tests were performed to evaluate the stress-strain, stress-rate of strain and time dependent characteristics.

The results from creep tests as strain-log time for peat and stress-rate of strain for calcareous soil are presented in Figure 7 and Figure 8.

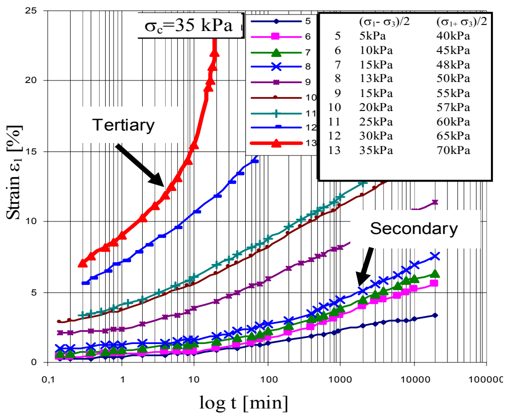

Figure 7. Strain versus log time for consolidated peat.

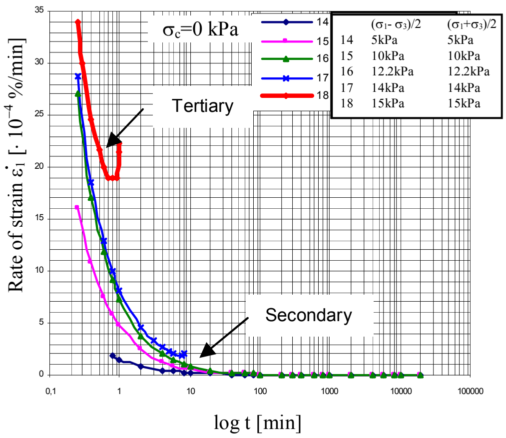

Figure 8. Rate of strain versus log time for *in situ* calcareous soil.

Laboratory test results indicated that the parameters describing secondary compression depend in considerable extent on effective stress level (Szymanski & Sas, 2003). Conventional creep settlements are regarded as being approximately linear in log time and are described as secondary settlement. In long-term tests there is sometimes a upwards curvature of the log time-settlement curve in the secondary compression phase. This phenomenon is sometimes called tertiary compression (Fig. 7).

The analysis of the development of vertical and horizontal strains in organic soils during the deformation process indicates significant creep of the soil skeleton. The part of strain (secondary phase) can be described by ε_s for a given consolidation stress depending on time t and deviatory stress as follows

$$\varepsilon_s = \eta_0 \cdot q^{\eta_1} \cdot t^{\eta_2} \tag{3}$$

where η_0, η_1, η_2 = empirical coefficients.

The obtained values of empirical coefficients to Eq. 3 for consolidated calcareous soil under $\sigma_c = 35$ kPa are $\eta_0 = 0.024$, $\eta_1 = 1.292$, and $\eta_2 = 0.069$ (Fig. 9).

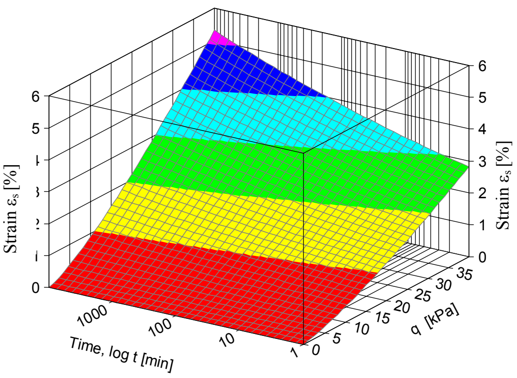

Figure 9. Relationship between secondary strain ε_s versus time t and deviatory stress q for consolidated calcareous soil.

It is important that the rate of strain can increase or decrease during the creep phase and depends on the level of deviatory stress (Fig. 8). When applied deviatoric stress is lower than deviatoric stress at failure the rate of strain decreases on the other hand when deviatoric stress is higher the rate of strain initially decreases than continuously increases until creep failure. Consolidation of subsoil significantly caused the decrease of the strain rate.

5 DISCUSSION OF THE RESULTS

Observations of the consolidation process in organic soils demonstrate large values and a non-linear character of deformation. Therefore, the prediction of consolidation performance in organic subsoil should be carried out by methods taking into account the variation of soil parameters and large strains analysis.
Field tests showed that vertical strip drains, despite earlier views, may effectively improve the bearing capacity of decomposed (amorphous) peat and calcareous soil for stage constructed embankments. Embankment subsoil composed of peat and calcareous soil layers, underlain by sand, settles more than twice as fast when the drains are installed. Acceleration of the consolidation process is much larger in the later phase of consolidation when the permeability of organic soils is essentially diminished.

In organic soils that demonstrate large horizontal displacements, an additional effect can be observed. This is the confining effect that consists in diminishing the horizontal displacement in the subsoil adjacent to the zone with drains. This, in turn, produces a slight increase of shear strength, thus improving conditions for stage construction.

Laboratory tests presented in this paper indicate that the strength parameters c' and φ' depend on the stress range, therefore the different values should be used for preconsolidated and normally consolidated stress state. It is important to note that deformation parameters E and E_u depend not only on the stress range but also on stress level.

Analysis of the development of vertical and horizontal strains in organic soils during the deformation process indicates significant creep of the soil skeleton. The part of strain can be described by ε_s for a given consolidation stress depending on time and deviatory stress.

6 CONCLUSIONS

Observations of the consolidation process in organic soils demonstrate large values and a non-linear character of deformation. The use of consolidation theory for the prediction of soil displacements under embankments requires taking into consideration the variable soil parameters depending on the effective stress level and preconsolidation phenomena.
The results of laboratory and field tests of organic soils indicate the different character of variation within the parameters. The passage from the overconsolidated stage to the normally consolidated state produces important changes in the values of strength parameters c' and φ', as well as in the deformation parameters E and E_u. The proper values of modulus numbers and exponents, which are valid for preconsolidated or normally consolidated state, should be applied. Moreover, the secondary compression described by ε_s should be predicted using parameters depending on time and effective stress components.

REFERENCES

Hartlen J., Wolski W. 1996: *Embankments on organic soils.* Amsterdam, Elsevier.

Koda, E., Szymański A. & Wolski W. 1993. Field and laboratory experience with the use of strip drains in organic soils. *Canadian Geotechnical Journal, vol.30, pp. 308-318.*

Larsson R. 1986. Consolidation of soft soils. *Report No 29*, Swedish Geotechnical Institute, Linkoeping.

Lechowicz Z. 1992. An evaluation of the increase in shear strength of organic soils under embankment loading. *Treatises and Monographs*, Warsaw Agricultural University Press, No. 162 (in Polish).

Lechowicz Z. 1994. An evaluation of the increase in shear strength of organic soils. *Proceeding of the Workshop on Advances in Understanding and modelling the Mechanical behaviour of Peat.,* Balkema, Rotterdam: 167-179.

Lechowicz, Z., Szymański A. & Wolski W. 1987. Effects of groundwater on embankment subsoil deformation. *Proceedings 9th European Conference on Soil Mechanics and Foundation Engineering*, Dublin, vol. 1, pp. 451-454.

Szymański A. 1991. The factors determining the deformations analysis of organic subsoil under embankment. *Treatises and Monographs*, Warsaw Agricultural University Press, No. 133 (in Polish).

Szymański, A. 1994. The use of constitutive soil models in consolidation analysis of organic subsoil under embankment. *Proceeding of the Workshop on Advances in Understanding and modelling the Mechanical behaviour of Peat.,* Balkema, Rotterdam: 231-240.

Szymański, A., Sas W. 2001. Deformation characteristics of organic soils. *Ann. of Warsaw Agricult. Univ. – Land Recl*. 32, pp. 117-126.

Szymański, A., Sas W. 2003. Deformation characteristics in consolidation analysis of organic soils. *Inżynieria Morska i Geotechnika*. Nr 3, pp. 156-159, (in Polish).

Wolski W., Szymanski A., Mirecki J., Lechowicz Z., Larsson R., Hartlen J., Garbulewski K. & Bergdahl U. 1988. Behaviour of two test embankments on organic soils. *Report No. 32*. Swedish Geotechnical Institute, Linköping.

ACKNOWLEDGMENTS

The study is a contribution to grant No. 3PO6S00223 sponsored by the Ministry of Scientific Research and Information Technology.