Annals of Warsaw Agricultural University – SGGW
Land Reclamation No 29, 2000: 41–49
(Ann. Warsaw Agricult. Univ. – SGGW, Land Reclam. 29, 2000)

Numerical analysis of organic soil behaviour during dilatometer test

ZBIGNIEW LECHOWICZ, SIMON RABARIJOELY
Department of Geotechnical Engineering, Warsaw Agricultural University, Poland

Abstract: *Numerical analysis of organic soil behaviour during dilatometer test.* This paper presents the results of numerical analysis of organic soil behaviour to obtain p_o and p_1 pressure measurements in dilatometer test. Numerical calculations were carried out for mud from the Nielisz test site where main dam embankment was constructed by stages. The numerical analysis was performed using Crisp program based on Modified Cam-Clay model. Results of numerical calculations have been used to assess the behaviour of organic soil during p_o and p_1 pressure measurements and evaluate the possibility of interpretation of dilatometer test data based on numerical analysis.

Key words: dilatometer test, organic soils, finite elements, stress analysis.

INTRODUCTION

Difficulties associated with the sampling of undisturbed soil specimens have led to the development of in situ penetration tests. Because of the complex behaviour of the soil when subject to the sophisticated loading conditions imposed by the in situ tests the interpretation of test data remains largely empirical (Yu et al. 1992). The uncertainties associated with the determination of the soil parameters from in situ tests increases when tests are performed in organic soils.

The Marchetti dilatometer is gaining acceptance as a routine sounding test for site investigation and assessment of geotechnical characteristics of soils. The dilatometer is a flat-bladed penetrometer 14 mm thick, 95 mm wide, 220 mm long, which has a 60 mm diameter flexible steel membrane centred on one side of the blade (Fig. 1) (Marchetti 1980). The dilatometer is driven to the desired depth and the membrane is expanded. The pressures at 0.05 and 1.1 mm membrane expansion are recorded and denoted *A* and *B* readings. A third pressure reading designed as *C* may also be obtained by controlled gas deflation after obtaining the *B*-reading and denotes the pressure at which the diaphragm recontacts the plane of the blade (Lutenegger 1988, Marchetti and Crapps 1981, Briaud and Miran 1991, Marchetti 1999). The readings are corrected for membrane stiffness and p_o, p_1 and p_2 represent the pressures required to expand the soil 0.05 mm, 1.1 mm and back to 0.05 mm. Based on the corrected reading p_o, p_1 and p_2 the dilatometer indexes i.e. material index I_D, horizontal stress index KD, dilatometer modulus E_D and pore pressure index U_D can be obtained (Marchetti 1980, Marchetti and Crapps 1981, Lutenegger 1988).

For better understanding of the dilatometer test process and to improved the interpretation of the test results numerical simulations have been carried out in the past (Baligh and Scott 1975, Whittle and Aubeny 1992, Smith and Houlsby 1995). A sensible interpretation of the dilatometer

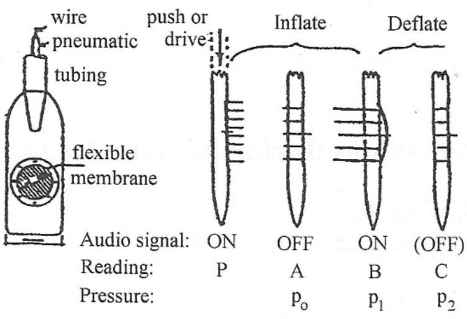

FIG. 1. Marchetti flat dilatometer

test data requires a more fundamental understanding of the soil behaviour during penetration as well as during membrane expansion. However most of the analysis were performed for evaluation of soil behaviour during dilatometer penetration (Yu et al. 1992, Huang 1989, Finno 1993).

This paper describes numerical analyses of organic soil behaviour during membrane expansion to obtain p_o and p_1 pressures. In analysis the results of laboratory and *in situ* tests carried out on soft organic subsoil at the Nielisz test site were used (Lechowicz and Rabarijoely 1997, Lechowicz et al. 1998).

METHOD OF ANALYSIS AND SOIL PROPERTIES

The numerical analysis was carried out using finite element program Crisp developed by Britto and Gunn (1987) based on Modified Cam-Clay model (Roscoe and Burland 1968). Numerical simulations of the dilatometer measurements of p_o and p_1 have been carried out taking into account consolidation of the soil around dilatometer blade. The expansion of the membrane was modelled as a continued loading of a circular area. Due to the symmetric nature of the problem only a half of the dilatometer membrane was analysed.

The soil parameters needed to define response with model are the isotropic compression index λ, the isotropic recompression index κ, the slope M of critical state line, $\Gamma - 1$ value which is void ratio on the critical state line in $e - \ln p'$ plane for a value of $p' = 1$, Poisson's ratio ν. The initial state of stress of the soil must also be specified, including initial effective stress, overconsolidation ratio OCR and initial void ratio e_o.

The numerical analysis was performed for mud from the Nielisz test site which has an organic content 20%, water content 120% and bulk density of soil 1.3 t/m^3. The soil parameters values used in numerical analysis obtained for mud are shown in Table 1 (Rabarijoely 2000). These parameter values were previously verified by comparison of measured and calculated displacements of organic subsoil loaded by embankment (Rabarijoely 2000).

TABLE 1. Cam-Clay parameters for mud from the Nielisz site

κ	λ	M	$\Gamma - 1$	ν
0.06	0.35	1.20	2.83	0.31

ANALYSIS OF NUMERICAL RESULTS

Numerical calculations presented in this paper were carried out for p_o and p_1 pressure measurements for mud with overconsoidation ratio $OCR = 1$ and 4 with coefficient of permeability $k_x = k_y = 10^{-8}$ and 10^{-9} m/s. Figure 2 shows computed total and effective horizontal stresses around dilatometer at p_o pressure measurement for coefficient of permeability $k_y = 10^{-8}$ and for overconsolidation ratio $OCR = 1$ and 4. As can be seen, the initial stress

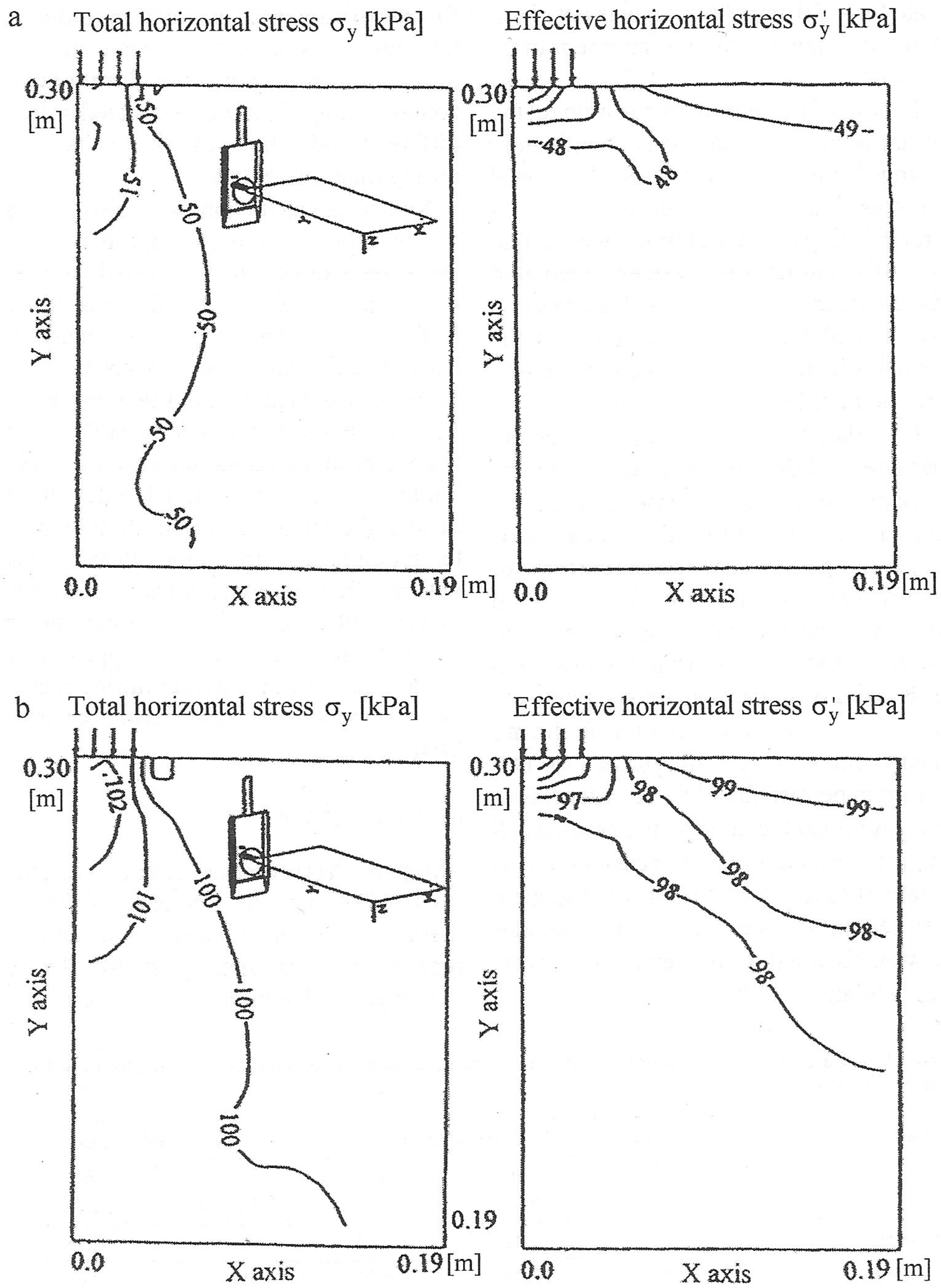

FIG. 2. Computed total and effective horizontal stresses around dilatometer at p_o pressure measurement for coefficient of permeability $k_y = 10^{-8}$ m/s, for overconsolidation ratio: a – $OCR = 1$, b – $OCR = 4$

state (σ_y = 50 and 100 kPa) was not changed too much during measurement of p_o pressure.

In case of p_1 pressure measurement the initial total stress state was significantly changed (Fig. 3). Values of total horizontal stresses obtained at the centre of the membrane during p_1 measurement were about 30–40% higher than values calculated during p_o measurement. With increase in overconsolidation ratio from 1 to 4 the total horizontal stresses were increased around membrane by about 30–60%.

Calculated values of the pore pressure parameter $\overline{B}$ defined as a ratio of excess pore pressure Δu to increase in total horizontal stress $\Delta\sigma_y$ around dilatometer blade at p_o and p_1 pressure measurements for coefficient of permeability $k_y = 10^{-8}$ and 10^{-9} m/s and for overconsolidation ratio OCR = 1 and 4 are shown in Figures 4 and 5. Results of numerical analysis indicate higher values of parameter $\overline{B}$ during measurement of pressure p_o than p_1. Decrease in permeability by one order causes not significant changes in parameter $\overline{B}$ values because time of measurement is relatively short. For the soil with the same permeability lower values of parameter $\overline{B}$ were obtained for higher value of overconsolidation OCR.

Results of numerical calculations indicate that pressures p_o and p_1 represent two different stress-strain states during horizontal loading. They can be treated as two different indication of the behaviour during dilatometer test.

Numerical calculations were also carried out in order to make comparison with measured values obtained from dilatometer test performed in organic soils at the Nielisz test site. An example of comparison between calculated and measured values of Δp pressures and dilatometer modulus E_D obtained in the virgin subsoil and at the end of first loading stage are shown in Table 2. It can be pointed out that in general the calculated values of dilatometer modulus E_D are higher than values obtained from dilatometer test. It indicates that sensible interpretation of dilatometer test data requires not only appropriate modelling of soil behaviour during membrane expansion but also during penetration.

CONCLUSIONS

This paper has presented a numerical analysis of the behaviour of organic soil during membrane expansion to obtain p_o and p_1 pressures in dilatometer test. Results of numerical calculations carried out for

TABLE 2. Calculated and measured values of Δp pressures and dilatometer modulus E_D for mud from the Nielisz site

Stage	Depth [m]	Calculated values		Measured values	
		Δp [MPa]	E_D [MPa]	Δp [MPa]	E_D [MPa]
Before loading	1.5	0.013	0.45	0.005	0.18
	3.0	0.027	0.95	0.019	0.66
After the 1 stage	1.5	0.056	1.95	0.047	1.64
	3.0	0.063	2.17	0.063	2.16

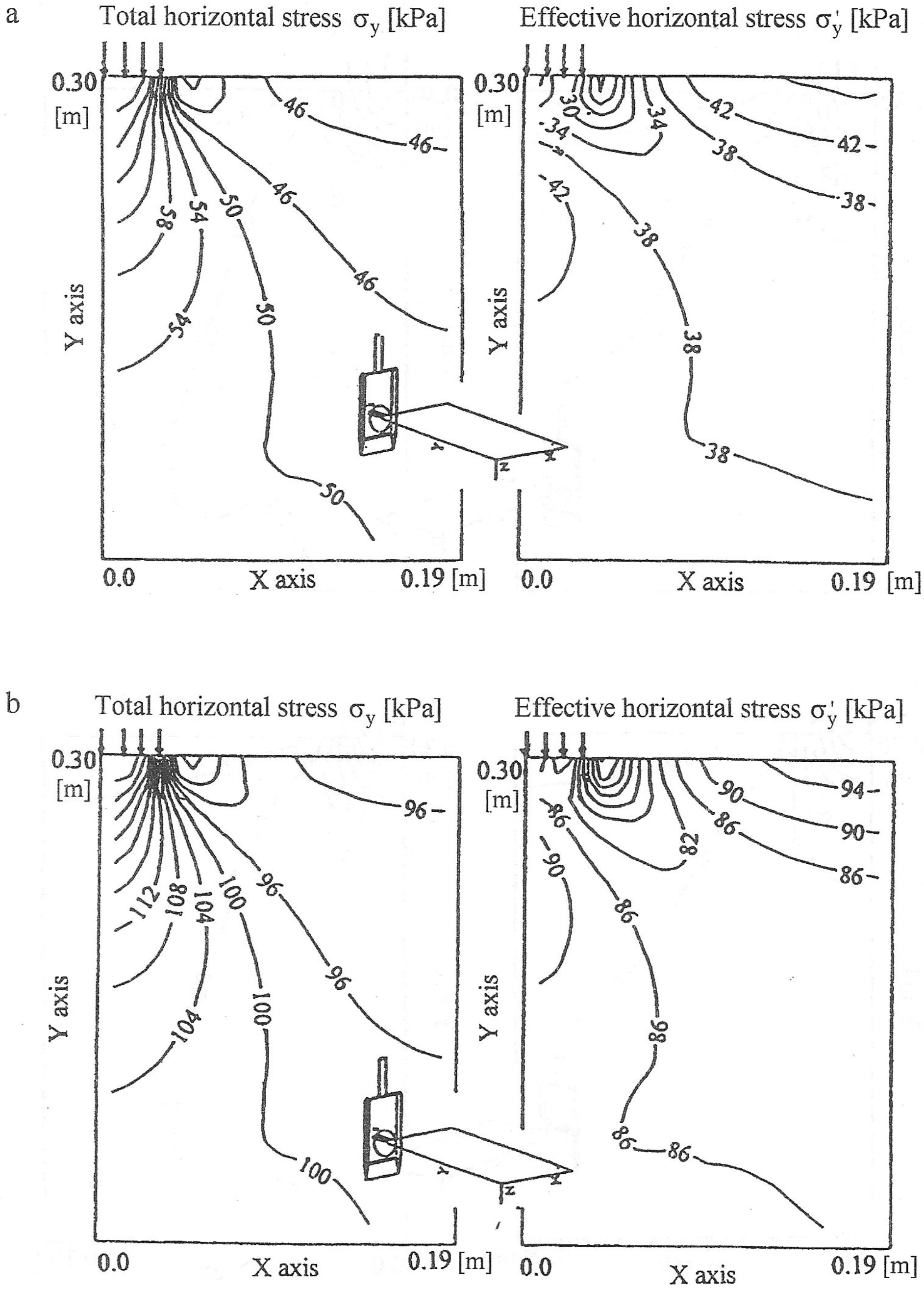

FIG. 3. Computed total and effective horizontal stresses around dilatometer at p_1 pressure measurement for coefficient of permeability $k_y = 10^{-8}$ m/s, for overconsolidation ratio: a – $OCR = 1$, b – $OCR = 4$

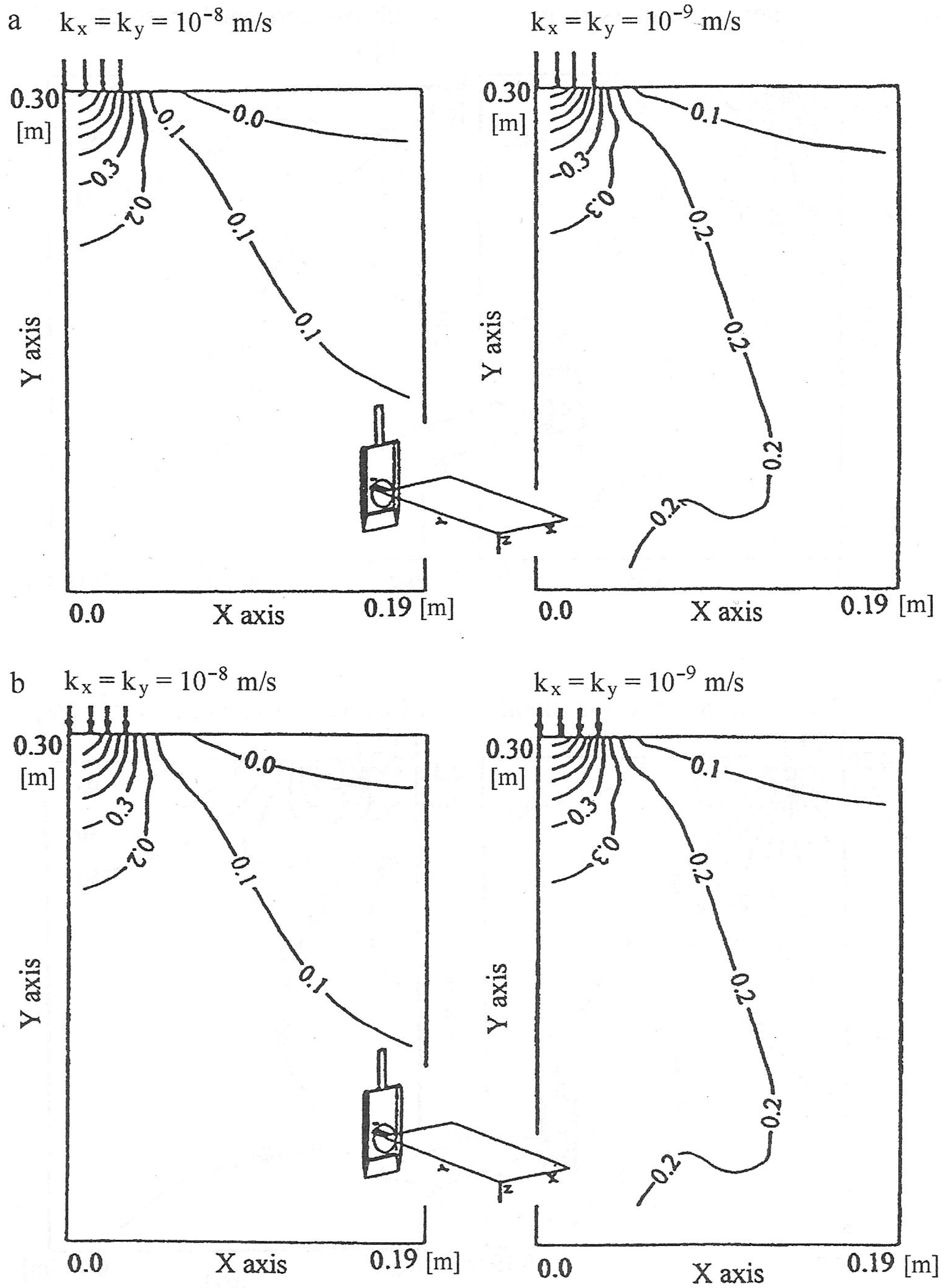

FIG. 4. Computed pore pressure parameter $\overline{B}$ around dilatometer at p_o pressure measurement for coefficient of permeability $k_y = 10^{-8}$ and 10^{-9} m/s, for overconsolidation ratio: a – $OCR = 1$, b – $OCR = 4$

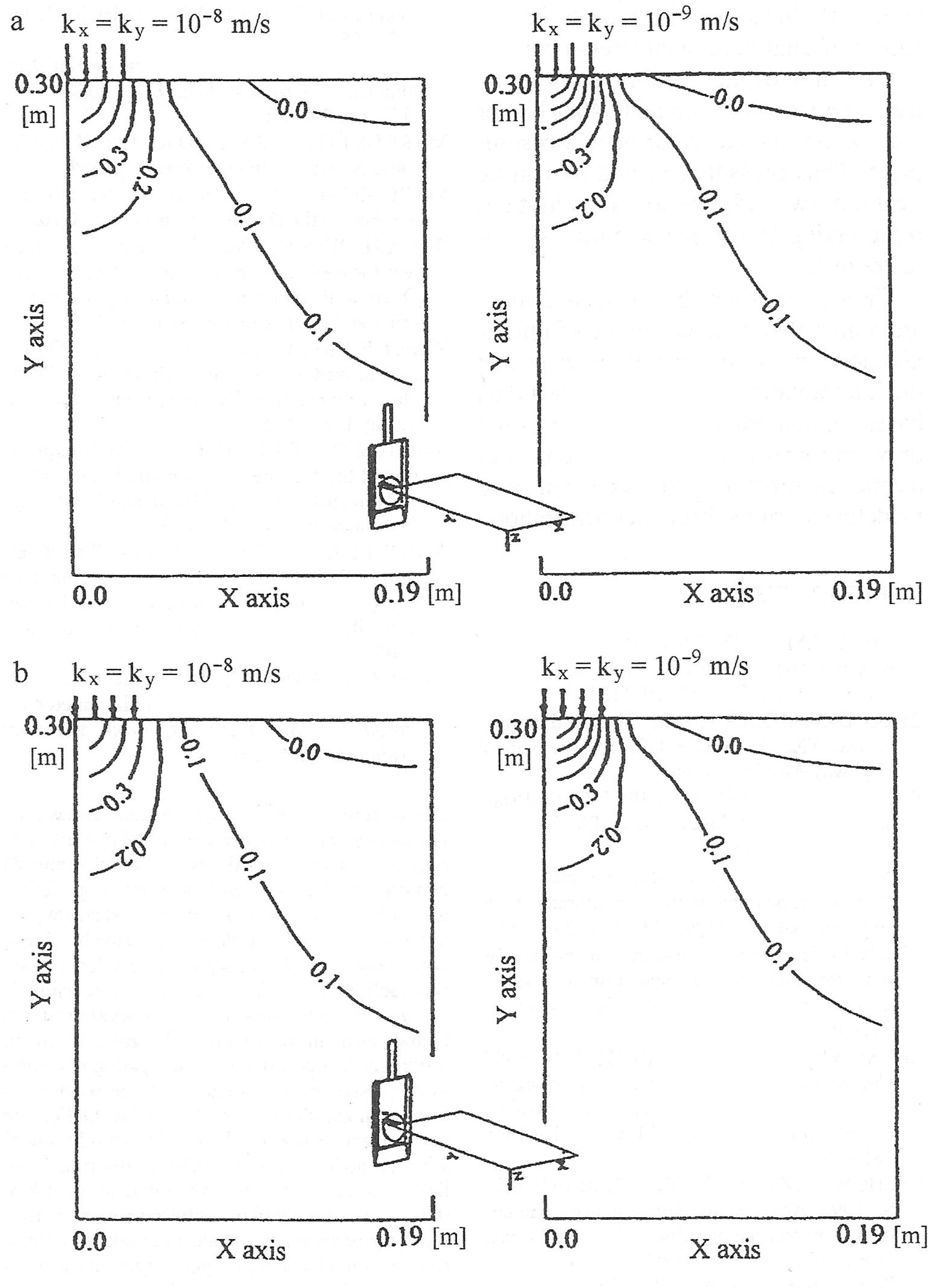

FIG. 5. Computed pore pressure parameter $\overline{B}$ around dilatometer at p_1 pressure measurement for coefficient of permeability $k_y = 10^{-8}$ and 10^{-9} m/s, for overconsolidation ratio: a – *OCR* = 1, b – *OCR* = 4

mud from Nielisz test site indicate that the values of total horizontal stress obtained at the centre of the membrane during p_1 measurement were about 30–40% higher than values calculated during p_o measurement. Thus pressures p_o and p_1 can be treated as two different stress-strain states representing soil response during dilatometer test.

The analyses show that calculated values are higher than values obtained from dilatometer measurements. It indicates that the interpretation of dilatometer test data based on numerical analysis requires not only appropriate modelling of behaviour during membrane expansion but also modelling during dilatometer penetration.

REFERENCES

BALIGH M.M., SCOTT R.F., 1975: Quasi-static deep penetration in clays. *J. Geotech. Eng. Div., ASCE*, 101, No GT11: 1119–1133.

BRIAUD G., MIRAN J., 1991: The flat dilatometer test. TX, 77843-3136 USA for The Federal Highway Administration.

BRITTO A.M., GUNN M.J., 1987: Critical state soil mechanics via finite elements. Ellis Horwood Limited, New York.

FINNO R.J., 1993: Analytical interpretation of dilatometer penetration through saturated cohesive soils. *Géotechnique*, 43, No 2, 241–254.

HUANG A.B., 1989: Strain path analysis for arbitrary three-dimensional penetrometers. *Int. J. for Num. and Anal. Meth. in Geom.* Vol. 13, pp. 551–564.

LECHOWICZ Z. and RABARIJOELY S., 1997. Use of dilatometer test in evaluation of organic subsoil strengthening. *Conf. on Recent Advances in Soft Soil Engineering*. Malaysia. Kuching: 185–196.

LECHOWICZ Z., BĄKOWSKI J., RABARIJOELY S., 1998: Analysis and performance of an embankment on organic subsoil. *Proc. XI Danube Europ. Conf. on Soil Mech. and Foun. Eng.*, Poreč, Croatia. Balkema, 223–226.

LUTENEGGER A.J., 1988: Current status of the Marchetti dilatometer test. *Proc. Int. Sym. on Penetration Testing ISOPT-1*, Orlando, 1, pp. 137–155.

MARCHETTI S., 1980: In Situ Tests by Flat Dilatometer. *J. Geotech. Eng. Div., ASCE*, 106, GT3, pp. 299–321.

MARCHETTI S., CRAPPS D.K., 1981: Flat dilatometer manual. *Internal report of GPE.*

MARCHETTI S., 1999: The flat dilatometer test. A report to the ISSMGE Committee TC16.

RABARIJOELY S., 2000: The use of dilatometer test for evaluation of organic soil parameters. Doctoral thesis (in polish). Faculty of Engineering and Environmental Science, WAU.

ROSCOE K.H., BURLAND J.B., 1968: On the generalized stress-strain behaviour of "wet" clay. *Engineering Plasticity*, Cambridge University Press, 535–609.

SMITH M.G., HOULSBY G.T., 1995: Interpretation of the Marchetti dilatometer in clay. *Proc. 11th Europ. Conf. on Soil Mech. and Foun. Eng.*, Copenhagen, 1, 1.247–1.253.

WHITTLE A.J., AUBENY C.P., 1992: The effects of installation disturbance on interpretation of in-situ tests in clays. *Productive Soil Mechanics, Wroth Memorial Symposium.* pp. 585–605.

YU H.S., CARTER J.P., BOOKER J.R., 1992: Analysis of dilatometer test in undrained clay. *Productive Soil Mechanics, Wroth Memorial Symposium*, pp. 621–631.

Streszczenie: *Numeryczna analiza zachowania się gruntu organicznego podczas badań dylatometrycznych.* W artykule przedstawiono wyniki obliczeń numerycznych zachowania się gruntu organicznego w okolicy łopatki dylatometru podczas wykonywania pomiarów dylatometrycznych. Ocenę wywołanych stanów naprężenia i ciśnienia wody w porach przeprowadzono przy pomiarze ciśnienia p_o i p_1. Obliczenia wykonano przy wykorzystaniu metody elementów skończonych z zastosowaniem programu numerycznego Crisp opartego na sprężysto-plastycznym modelu gruntu ze wzmocnieniem typu zmodyfikowany Cam-Clay. Obliczenie numeryczne przeprowadzono dla namułu stanowiącego podłoża zapory czołowej zbiornika Nielisz na rzece Wieprz w województwie lubelskim (tab. 1). Analiza wyników obliczeń numerycznych stanu naprężenia i odkształcenia podczas pomiarów dylatometrycznych wykonanych dla namułu z Nielisza świadczy o niewielkich zmianach początkowego stanu naprężenia wywołanych pomiarem p_o w porównaniu z istotnymi zmianami stanu

naprężenia przy pomiarze p_1 (rys. 2 i 3) Wartość składowej pionowej naprężenia całkowitego uzyskane w środku membrany przy pomiarze p_1 w stosunku do naprężeń uzyskanych przy pomiarze p_o są większe o 30–40%. Przeprowadzona analiza numeryczna wskazuje, że ciśnienia p_o i p_1 reprezentują reakcję gruntu podczas poziomego obciążenia przy dwóch istotnie różnych stanach naprężenia i odkształcenia. Wyniki obliczeń numerycznych wykazały większe wartości modułów dylatometrycznych E_D w stosunku do wartości uzyskanych na podstawie badań dylatometryczych (tab. 2.) Fakt ten wskazuje, że przy interpretacji wyników badań dylatometrycznych na podstawie obliczeń numerycznych konieczne jest uwzględnienie zarówno zmian wywołanych etapem pogrążania jak i wykonywania pomiarów.

MS. received September 26, 2000

Author's address:
Zbigniew Lechowicz
Katedra Geoinżynierii
Wydział Inżynierii i Kształtowania Środowiska
SGGW
02-787 Warszawa, ul. Nowoursynowska 166
Poland