SHEAR PARAMETERS OF VARVED CLAY

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Abstract

Investigations on changes of shear parameters of varved clay with different approaches in triaxial test and direct shear are subject of the following paper. Also statistical estimation of physical parameters of clay in soil massif has been presented and the usefulness of normal distribution in selecting adequate probablistic model of variability distribution of shear resistance coefficient in direct shear test has been evaluated.

Introduction

Investigation on varved clay parameters have their special position in discussions of the geotechnicians. It is due to pronounced anisotropy of their structure. In case of these soils two parallel problems require further examinations, namely: determination of representative strength and physical parameters for considered fragment of the subsoil and qualitative determination of the influence of the factors deciding the shear resistance. In solving the former of the problems most often statistical methods are applied.

Factors determining shear resistance of cohesive soil have been described by MITCHELL (1976) in the following way:

$$T = F(e, E, \sigma, \Phi_u, c_u, H, \varepsilon, \dot{\varepsilon}, t, S) \tag{1}$$

where: e — void ratio, E — ambient condition, e.g. type of water in pores, temperature, saturation degree, σ — mean principal stress, Φ_u — angle of internal friction, c_u — cohesion, H — stress history, t — time, ε — strain, $\dot{\varepsilon}$ — strain rate, and S — structure.

For varved clays the equation (1) was supplemented by MŁYNAREK and NIEDZIELSKI (1979) with two factors: direction of interbedding surface, and kind of soil constituting the interbedding. The parameters occurring the equation (1) are not independent variables. So far we also do not know all analytical functions which would quantitatively describe relation between shear resistance and each variable from the equation (1). Better situation we have in case of

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estimating strength of varved clay by means of static sounding, since partial functions resulting from equation (1) have been presented in works of CARPENTIER (1982), MŁYNAREK, NIEDZIELSKI (1982). In this paper an attempt has been made at evaluating effect of stress history and mean principal stress on shear resistance of varved clay. Also the usefulness of shear resistance has been examined. These factors seemed to be particularly important, for varved clay constitutes a slope of the brick-field excavation in Kotowo near Poznań. Different stages of excavation imply different stress in clay.

Statistic evaluation of physical parameters of clay. Methods of investigating shear parameters

Samples for investigations were taken from the wall of deep excavation. Direction of sampling was perpendicular to interbeddings occurring in soil massif. Some samples for triaxial test were taken diagonally to interbedding. Generally, examination of physical parameters was carried out on 120 samples (Table I). Analysed varved clay belongs to Tertiary deposits. Not quite clear is the character of stress history for this clay, thus examinations of K_0 coefficient were carried out. Dominating grain fraction proved to be the one approaching dimension up to 0.002 mm, so in replication test of grain size distribution high value of variability coefficient was obtained (Table I). Analyses identified these fraction as silt or clay. For characteristic granulation coefficient we can assume sum of clay and silt fractions which showed very high recurrence of determination (Table I). Examinations of mineralogical composition of clay fraction carried out by means of derivatographical and roentgenographical methods showed that clay fraction is a mixture of kaolinite, illite and montmorillonite (NIEDZIELSKI, 1979). Determined mean values of

Table I

Statistical estimation of properties of analysed clay

Properties		n	Mean	S_x	CV %	Confidence limits	
γ_d	kN/m³	120	14.41	0.8070	5.59	14.27	14.56
w	%	120	37.84	4.2112	11.13	37.08	38.59
Clay	%	36	45.50	16.2577	35.73	40.19	50.81
Sand	%	36	13.33	3.1259	23.44	12.31	14.35
Silt + clay	%	36	86.69	3.1059	3.58	85.68	87.71

CV — coefficient of variation
n — replication number
S_x — standard deviation

Atterberg Limits were: liquid limit 42.7%, plastic limit 20.7%, shrinkage limit 18.2%.

Examination of shear resistance was carried out in triaxial apparatus and direct shear apparatus. Triaxial test was made according to two procedures, in the first group (line *c*, Fig. 1) as a conventional shear test on samples of 35.6 mm in diameter with measurement of pore pressure at $\sigma_2 = \sigma_3$ const and $\sigma_1 > \sigma_3$. In the second group: investigations were made on samples of 100 mm in diameter and height of 235 mm. The examination was carried out in closed system with measurement of pore pressure. After reaching the state of stress K_0, in the following experiments the stress was assumed as $\sigma_1 = 100$, 150, 200, 250, 300 KPa and the stress σ_1, was being increased at $\sigma_3 =$ const., fill destruction (lines a and b, Fig. 1). In this experiment two groups of samples were selected: samples "*a*" in which the direction of interbedding was the same as that of the stress σ_3, and samples "*b*" in which this direction was similar to the direction of potential surface of destruction (Fig. 1). These experiments were made in the Laboratory of the Department of Geotechnique, Technical University, Budapest.

Samples in direct shear test were oriented in such a way that the direction of interbedding was the same as the shear surface which corresponded to procedure "*b*" in triaxial shear test. In direct shear test two procedures of examination were applied CASE I (Fig. 2) in which 30 replications of measurement of shear resistance were made at the values $\sigma_n^1 = \sigma_{v0}$ (overburden pressure), $\sigma_n^2 = 2\sigma_{v0}$, $\sigma_n^3 = 3\sigma_{v0}$, and CASE II where after reaching maximal value $(\tau_n \cdot \sigma_n^{-1})$ shear on the same sample was repeated, with σ_n^1 increased to value $2\sigma_{v0}$ and once more it was sheared at $\sigma_n^2 = 3\sigma_{v0}$. This experiment was made in 30 replications. Shearing next 30 samples started at $\sigma_n^2 = 2\sigma_{v0}$ and for the last portion of 30 samples shear started at $\sigma_n^3 = 3\sigma_{v0}$. Interpretation of shear parameters was given in total stress.

Evaluation of the model of probablistic variability distribution of shear resistance of clay

Knowledge of probablistic model of variability distribution of shear resistance has, besides its cognitive aspect, important practical meaning. Since known probablistic model facilitates determination of distribution momenta, being representative values of shear resistance for investigated layer of subsoil. In this paper we limited our discussion to evaluation of the possibility of applying normal distribution as a model of shear resistance variability distribution, whereas in the paper by MŁYNAREK, HORVÁTH and TSCHUSCHKE (1984) detailed analysis of this problem is presented.

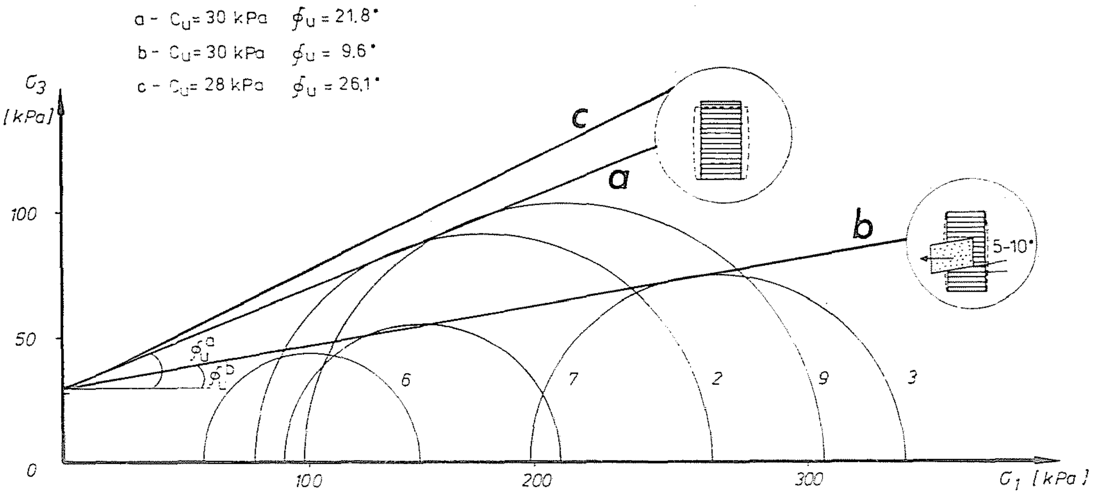

Fig. 1. Triaxial Test Results for analysed varved clay; c-conventional triaxial, a, b — Triaxial test with large diameter samples

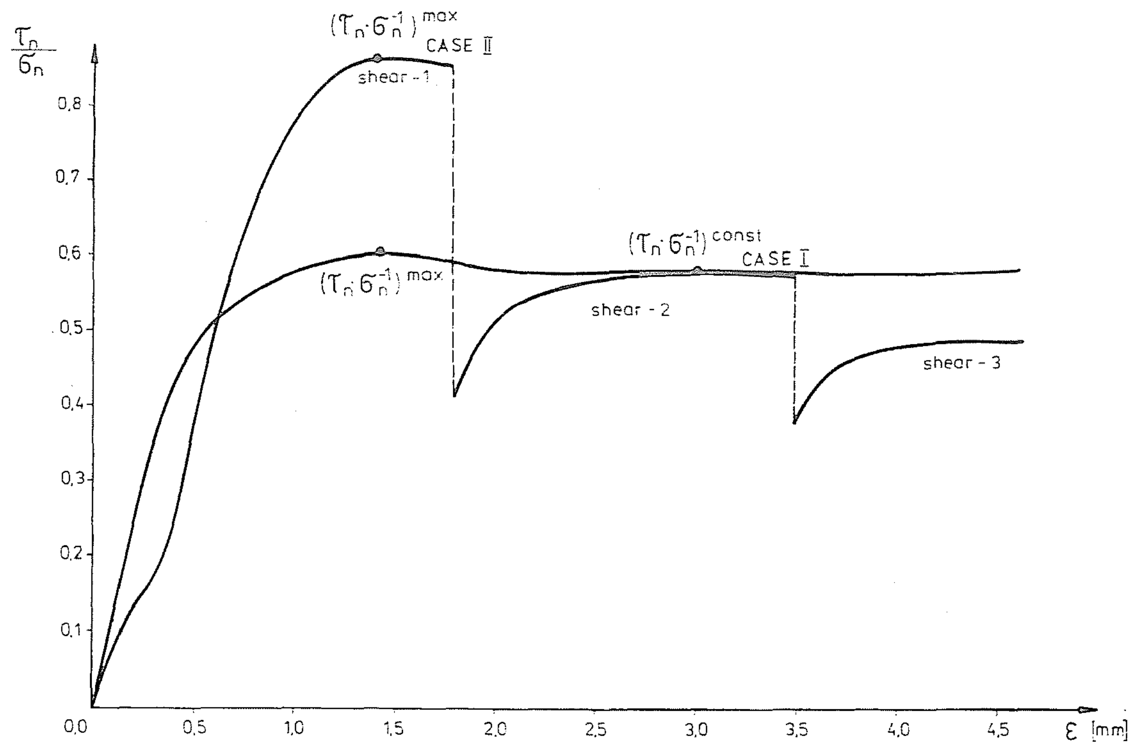

Fig. 2. Investigation procedures in the direct shear test

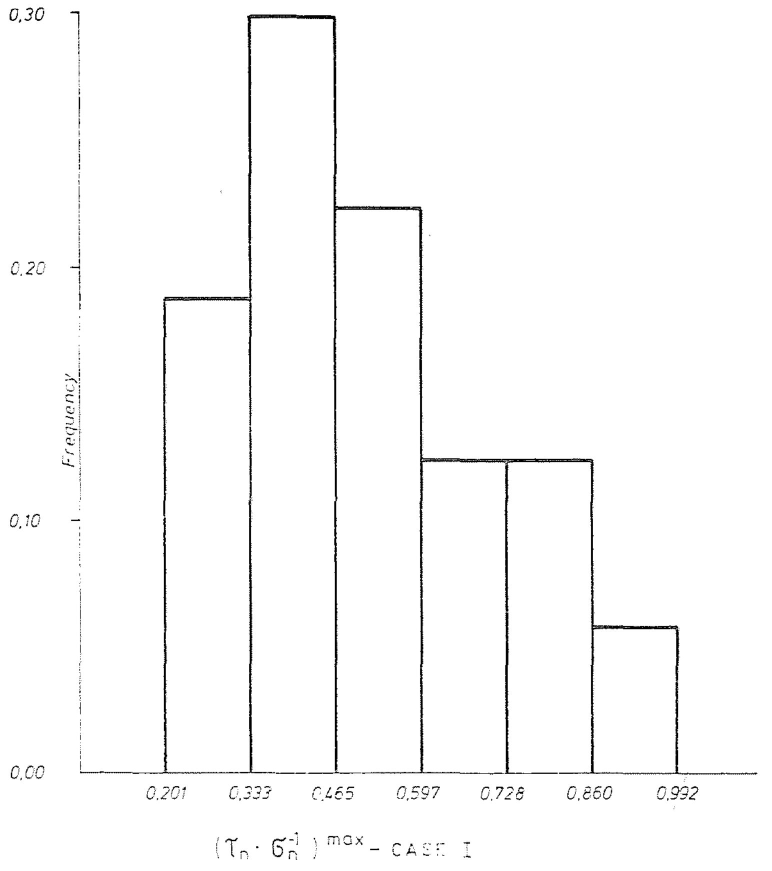

Fig. 3. Frequency distribution of max. value of coefficient of shear resistance (CASE I)

From Figs 3 and 4 it is seen that histogrammes of variability $(\tau_n \cdot \sigma_n^{-1})^{max}$ and $(\tau_n \cdot \sigma_n^{-1})^{const}$ show considerable asymmetry. For resistance coefficient in the procedure CASE II — shear 2 increase in asymmetry of distribution was found.

Kołmogorow—Smirnow compatibility test showed that for the three discussed cases there is no reason to reject hypothesis that normal distribution is an adequate variability distribution of shear resistance, whereas Pearson's test X^2 overruled hypothesis about normality of distribution for $(\tau_n \cdot \sigma_n^{-1})^{max}$ CASE I and $(\tau_n \cdot \sigma_n^{-1})^{const}$.

Variability coefficient calculated from momenta of normal distribution for each examined value of shear resistance coefficient, was high and amounted to 37.5%.

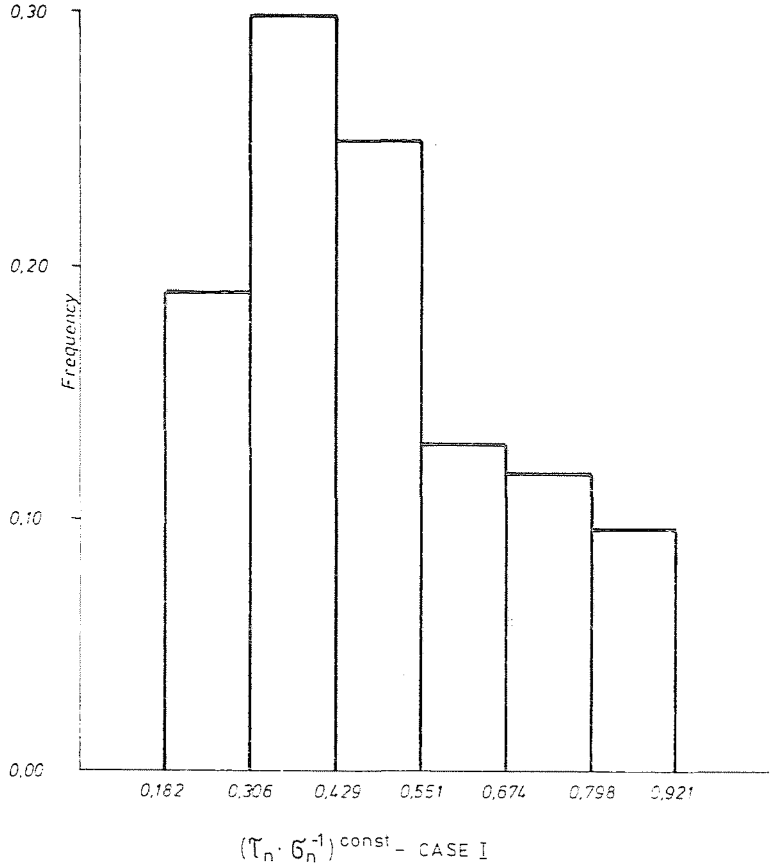

Fig. 4. Frequency distribution of constant value of coefficient of shear resistance (CASE I)

Statistical evaluation of changes in shear parameters of clay

From equation (1) results that to determine effect of mean principal stress and stress history on shear resistance, and consequently on shear parameters, the other variables must be kept on constant level during the experiment. From dimensional analysis of equation (1) also results that dimensionless product $\dot{\varepsilon}_t \cdot \dot{\varepsilon}_d^{-1}$, where: $\dot{\varepsilon}_t$ — strain rate at triaxial test, and $\dot{\varepsilon}_d$ — strain rate at direct test should be kept on constant level. This product equalled 1. 4.

From Table II results that basic physical parameters of clay samples in CASE I and CASE II did not differ significantly on the significance level $\alpha = 0.05$. Whereas values of shear resistance differed in each procedures and thus we can assume that changes in shear parameters are in further analysis explained by variability of the two above given factors. From the experiment

Table II

Comparison of mean values of physical parameters for two cases of investigations

Properties	Mean value		Value of statistic "F"		Decision
	CASE I	CASE II	Fobl	F 0.05	
Water content %	36.81	40.86	25.06	3.92	—
Effective unit. weight of soil kN/m^3	14.49	13.86	2.07	3.92	+
Coefficient of porosity	0.372	0.409	17.26	3.94	—
Clay content %	41.07	59.00	9.24	4.12	—
Sand content %	13.39	13.12	0.044	4.13	+
Clay + silt content %	86.61	86.83	0.024	4.15	+

Table III

Comparison of mean values of coefficient of shear resistance for CASE-II of investigation

	Mean value of dimensionless shear parameter $(\tau_n \cdot \sigma_n^{-1})^{\max}$	Value of statistic F		Decision
		Fobl	F 0.05	
CASE II, shear — 1	1.0917	30.218	4.01	—
CASE II, shear — 2	0.5979	6.991	4.01	—
CASE II, shear — 3	0.4439	59.710	4.01	—

+ not significant differences between mean values on $\alpha = 0.05$ level
— significant differences between mean values on $\alpha = 0.05$ level

of conventional triaxial and triaxial on closed system (Fig. 1) results that if potential shear surface was not equal to the direction of interbedding surface then obtained shear parameters differed between each other only slightly (lines "*c*" and "*a*"). For the samples in which shear surfaces were equal to the direction of interbedding, the value of the angle of internal friction decreased by 56% whereas, as it was expected, cohesion did not change. The result obtained is compatible to the results obtained by Mitchell (1974) and Młynarek and Niedzielski (1979). From triaxial test we can conclude that the clay belongs to overconsolidated clays (Fig. 5).

Very interesting observations can be made from direct shear experiment. Obtained values of the angle of internal friction in CASE I examination are highly compatible to the angle of internal friction from triaxial test for procedure "*b*" (Fig. 1 and 5). Only the value of cohesion is higher. However, it is generally known that higher values of cohesion are obtained from direct test than from triaxial shear test. Analysis of shear parameters after reaching peak strength and the following repeated shears showed that the value of

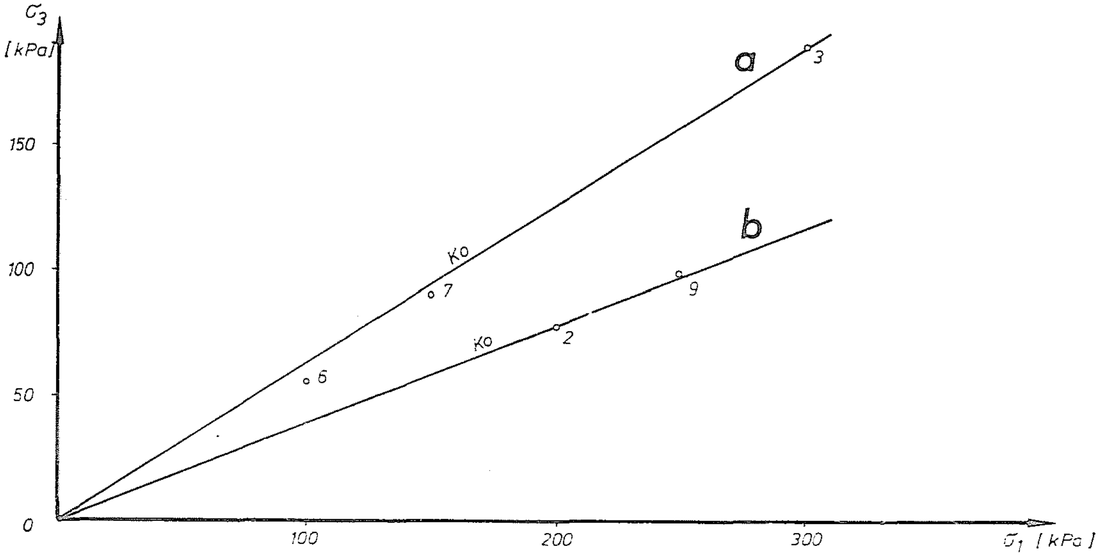

Fig. 5. K_0 — line for two types of soil samples

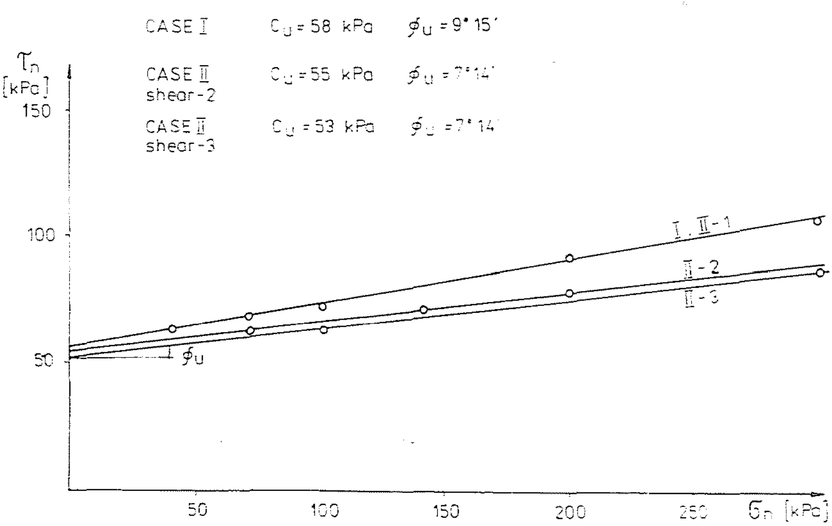

Fig. 6. Direct shear test results for two cases of investigations of varved clay

cohesion decreased in 2nd shear by 5.2%, in 3rd shear by 8.7%, whereas that of the angle of internal friction decreased by 21.8% (Fig. 6). In the 3rd shear the angle of internal friction did not change. Stability of the value of cohesion in the process of multiple shear proves that the surface of weakening continuity of clay structure which is created by interbedding, contributed to quick termination of the processes of structure orientation, thrust shears, Reidel shears.

Conclusions

Analysis of changes in shear parameters of varved clay in soil massif and in result of different loading of clay samples lets us draw the following conclusions:

I) anisotrophy of clay parameters causes considerable variability of shear parameters of the clay layer in subsoil. Estimated variability coefficient for great statistical sample for maximal and residual value of shear resistance was 37.5%.

II) examinations of variability distribution of shear resistance coefficient showed that the model of normal distribution can be assumed as approximate model. Further analysis of this problem should suggest another adequate model.

III) of the two analysed factors deciding shear strength of varved clay, namely the direction of interbedding in relation to potential shear plane, and the mean stress connected with the state of stress in the sample, definitely more significant is the effect of the direction of interbedding. This observation seems to be of particular importance in designing investigations of shear parameters of the problem of stability of varved clay slopes.

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