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THE ANALYSIS OF FACTORS INFLUENCING THE VALUES OF SOIL SHEAR STRENGTH PARAMETERS OBTAINED BY DIRECT SHEAR TEST

GIANG NGUYEN

Department of Geotechnics, Faculty of Civil Engineering, University of Žilina,
Komenského 52, 010 26 Žilina, Slovakia. Phone: (00421) 41 513 5759, fax: (00421) 41 72 33 502,
e-mail: giang.nguyen@fstav.uniza.sk

Abstract: The paper deals with some factors which influence the values of soil shear strength parameters, obtained by direct shear test. The effects of shear speed, shear area changing, conventional test ending linear deformation as well as the number of specimens on test results have been analysed. The analysis is based on actual documents concerning direct shear test, such as the European Technical Commission document ETC5-F2.97, Polish Standard PN-88/B-04481 and Slovak Technical Standard STN 72 1030. The results of direct shear tests of kaolin obtained from the ceramic factory Tułowice and clay from Niepołomice are presented for illustration purposes.

Streszczenie: Opisano pewne czynniki, które wpływają na wartości parametrów wytrzymałości podłoża na ścinanie otrzymanych w teście bezpośredniego ścinania. Przeanalizowano wpływ szybkości ścinania, zmiany obszaru ścinania, umownego zakończenia testu uwzględniającego deformację liniową i liczby próbek na wyniki testu. Analiza opiera się na rzeczywistych dokumentach dotyczących testu bezpośredniego ścinania, takich jak dokumentacja techniczna ETC5-F2.97 Komisji Europejskiej, Polska Norma PN-88/B-04481 i Słowacka Norma Techniczna STN 72 1030. Wyniki testu bezpośredniego ścinania dla kaolinu z zakładów ceramiki Tułowice i iłu z Niepołomic ilustrują powyższe zależności.

Резюме: Описаны некоторые факторы, влияющие на значения параметров сопротивления основания срезу, полученных в тесте непосредственного срезывания. Проведен анализ влияния скорости срезывания, изменения области срезывания, условного времени окончания теста, учитывающего линейную деформацию и количество проб на результаты теста. Анализ базирует на действительных документах, касающихся теста непосредственного срезывания, таки как техническая документация ETC5-F2.97 Европейской Комиссии, Польских Стандартов PN-88/B-04481 и Словацких Технических Стандартов STN 72 1030. Результаты теста непосредственного срезывания для каолина из керамического завода Туловице и ила из Неполомиц иллюстрируют вышеуказанные зависимости.

LIST OF SYMBOLS

Geotechnical parameters

w – water content [%]
w_L – liquid limit [%]
w_P – plastic limit [%]
φ – angle of internal friction [°]
c – cohesion [kPa]
c_s – cohesion obtained by direct shear test in shear apparatus acc. to PN-88/B-04481 [kPa]
Φ_s – friction angle obtained by direct shear test in shear apparatus acc. to PN-88/B-04481 [°]

φ_{eff} – effective angle of peak shear strength acc. to STN 72 1030 [°]
c_{eff} – effective cohesion acc. to STN 72 1030 [kPa]
φ_r – effective angle of residual shear strength acc. to STN 72 1030 [°]
c_r – effective residual cohesion acc. to STN 72 1030 [kPa]

Geometrical values

a – specimen side length at $\varepsilon = 0\%$ [mm]

Calculated values

v – maximum allowable rate of shear [mm/min]
s_f – estimated horizontal shear deformation upon failure acc. to ETC5-F2.97 [mm]
t_f – time to failure acc. to ETC5-F2.97 [min]
ε – linear deformation [–]
l_f – shear deformation reached at maximum value $\tau = \tau_{\max}$ acc. to STN 72 1030 [mm]
t_f – time necessary to reach maximum value $\tau = \tau_{\max}$ acc. to STN 72 1030 [s]
H – the longest drained path [mm]
c_v – coefficient of consolidation [mm^2/s]
τ – shear stress [kPa]
$\tau_{\max}$ – maximum shear stress [kPa]
σ – normal stress [kPa]
P – horizontal shear force [kN]
A – initial plan area of the specimen [m^2]
τ_f – shear strength of specimen [kPa]
$Q_{\max}$ – maximum shear force [N]
r – displacement of apparatus frame at the moment the maximum shear force is reached [mm]
Q_{10} – maximum shear force at $\varepsilon = 10\%$ [N]
τ_{fi} – shear strength of each specimen [kPa]
N – number of specimens involved in calculation [–]
N – normal force [kN]
A – cross area of sample [m^2]
T – shear force (force against shearing) in [kN]
n – number of specimens [–]
r – correlation coefficient [–]
r_a – critical values of correlation coefficient [–]
R^2 – square of the correlation coefficient [–]

1. INTRODUCTION

In many tasks of geotechnical practise, we often need to know the values of soil shear strength parameters: angle of internal friction and cohesion. Those parameters can be obtained by in-situ testing and also in laboratories, using many kinds of tests. One of the well-known tests is the direct shear test.

Though direct shear test has some advantages such as simplicity and ease of specimen preparation, it has more disadvantages, the main one being that drainage conditions cannot be controlled [2]. Since during the test, only the total normal stress is determined and pore water pressure is normally not measured, we do not know the value of an effective normal stress. Shear stress on the failure plane is also not uniform and failure occurs progressively from the edges towards the centre of the specimen. The area under the shear and vertical loads does not remain constant throughout the test. The test result is obtained by statistical evaluation of a certain number of specimens, so it can be dependent on the latter.

Test procedures following the various standards are designed so as to minimize the influence of the aforementioned factors on the test results. Since the procedures of direct shear test being based on various documents differ from one another, it will be useful to analyse them using actual documents. In this paper, relying on ETC5-F2.97 [7], PN-88/B-04481 [6] and STN 72 1030 [9], we will deal with influence of shear rate, shear area changing, conventional test ending linear deformation as well as the number of specimens on test results.

2. INFLUENCE OF SHEAR SPEED

By ETC5-F2.97, the minimum time to failure t_f, i.e., to mobilization of maximum shear resistance of the specimen, is calculated by the formula:

$$t_f = 12.7 t_{100}. \tag{1}$$

Maximum rate of shear is then determined by the formula:

$$v = s_f / t_f \tag{2}$$

where:

v – maximum allowable rate of shear (e.g., in mm/min),

s_f – estimated horizontal shear deformation upon failure [mm],

t_f – time to failure [min].

For saturated fine-grained (cohesive) soils, the maximum rate of displacement shall not exceed the value calculated by formula (2). For coarse-grained (cohesionless) soils the rate of displacement shall not exceed 0.5 mm/min.

By ETC5-F2.97, the test can be terminated when the strain at peak load is clearly exceeded or when the horizontal displacement has reached 20% of the diameter or the width of the specimen.

By PN-88/B-04481, for low cohesive soils (clayey sand, silt and silty sand) the maximum rate of displacement shall not exceed 1–1.2 mm/min, for other cohesive soils, the rate of displacement shall not exceed 0.05 mm/min.

By PN-88/B-04481, in the case where in three subsequent readings the shear force remains constant or decreases, the test will be stopped, otherwise the shearing has to continue until the shear displacement reaches linear deformation $\varepsilon = 10\%$.

By STN 73 1030, the shear rate (v) in mm per second is calculated by the formula:

$$v = \frac{l_f}{t_f} \tag{3}$$

where:

l_f – shear deformation [mm] reached at maximum value $\tau = \tau_{\max}$, taken from table 2 of the standard (l_f is from 0.5 to 2 mm for soil with firm consistency; from 2 to 4 mm for soil with stiff consistency, and more than 4 mm for soil with soft consistency),

t_f – time [s] necessary to reach maximum value $\tau = \tau_{\max}$, obtained from the formula:

$$t_f = \frac{10.H^2}{c_v} \tag{4}$$

where:

H – the longest drained path, which is half the sample height for the case of two-sided drainage [mm],

c_v – coefficient of consolidation [mm^2/s].

If the coefficient of consolidation is unknown, it is possible to apply the shear speed, as given in table 3 of the standard (for sand and silty sand the highest speed is 0.25 mm/min; for clay, with $w_L \geq 50\%$, the highest speed is 0.002 mm/min). The values in the aforementioned table 3 are valid for a sample with the height of up to 12 mm only. For samples of more than 12 mm in height, it is necessary to prove that the pore water pressure does not influence the highest value of shear stress.

By STN 73 1030, specimen is sheared until shear displacement reaches one tenth of its size (specimen diameter or side).

As we can see, ETC5-F2.97 and STN 73 1030 use consolidation theory to calculate the maximum shear speed. ETC5-F2.97 does not specify how to obtain the values of shear deformation at failure s_f, the table values of which can be found in STN 73 1030. The maximum shear speed for cohesionless soils prescribed by documents also varies (ETC5-F2.97 – 0.5 mm/min, PN-88/B-04481 – 1–1.2 mm/min, STN 73 1030 – 0.25 mm/min).

Specifying the speed it is expected to obtain effective parameters of soil shear strength. In practise, e.g., in the case of landslide, the shear speed is in many cases higher than conventional low speed applied to obtained effective parameters of soil shear strength. With the shear speed being higher, the pore water pressure is expected not to be well dissipated, which fact will exert influence on the parameters of soil shear strength. It is for this reason that we have chosen to test the same soils at a shear speed of 0.01 mm/min (slow test) and 1 mm/min (quick test), for more detail see section 6.

3. INFLUENCE OF SHEAR AREA CHANGING

The parameters of shear strength can be calculated in accordance with ETC5-F2.97 using a graph, where the value of the peak shear stress τ_f is drawn as the ordinate against the corresponding consolidation stress σ as the abscissa, both to the same scale. By the same document, the shear stress on the surface of shear τ is calculated from each dataset obtained during the shear test by the formula:

$$\tau = \frac{P}{A} \tag{5}$$

where:

P – horizontal shear force (e.g., in kN),

A – initial plan area of the specimen [m^2].

In note No. 12 of the document, the continual change in the area of contact in the shear box is not normally taken into account.

By PN-88/B-04481, the shear strength of specimen τ_f is to be calculated in kPa:

a) *for linear strain ε < 10% by the formula*:

$$\tau_f = \frac{Q_{\max}}{a.(a-r)}.10^3 \tag{6}$$

where:

$Q_{\max}$ – maximum shear force [N],

r – displacement of apparatus frame at the moment the maximum shear force is reached [mm],

a – specimen side length at $\varepsilon = 0\%$ [mm].

b) *for linear strain ε = 10% by the formula*:

$$\tau_f = \frac{Q_{10}}{0.9.a^2}.10^3 \tag{7}$$

where Q_{10} – maximum shear force at $\varepsilon = 10\%$ [N].

After obtaining the values of τ_f for at least five specimens, it is necessary to draw a graph of τ_f vs. σ (by linear approximation) and to check whether deviation of point (σ, τ_f) is more than 25% of the value of τ_f. If yes, it is necessary to exclude that specimen from evaluation and use the next one to ensure that the conditions are fulfilled. The cohesion and angle of friction are calculated using coefficients a and b:

$$a = \frac{N\sum_{i=1}^{N}\sigma_i\tau_{fi} - \sum_{i=1}^{N}\sigma_i\sum_{i=1}^{N}\tau_{fi}}{N\sum_{i=1}^{N}(\sigma_i)^2 - \left(\sum_{i=1}^{N}\sigma_i\right)^2}, \tag{8}$$

$$b = \frac{\sum_{i=1}^{N}(\sigma_i)^2 \sum_{i=1}^{N}\tau_{fi} - \sum_{i=1}^{N}\sigma_i \sum_{i=1}^{N}\sigma_i\tau_i}{N\sum_{i=1}^{N}(\sigma_i)^2 - \left(\sum_{i=1}^{N}\sigma_i\right)^2}. \tag{9}$$

The cohesion c_s is calculated in kPa with an accuracy of 1 kPa by the formula:

$$c_s = b. \tag{10}$$

The angle of friction Φ_s is calculated in degrees with an accuracy of 0.1° by the formula:

$$\Phi_s = \text{arc tg}\, a. \tag{11}$$

The meaning of symbols from equations (8) through (11):
τ_{fi} – shear strength of each specimen [kPa],
σ_i – normal stress [kPa],
N – number of specimens involved in calculation.

By STN 73 1030, the normal effective stress (σ_{eff}) in kPa is calculated by the formula:

$$\sigma_{eff} = \frac{N}{A} \tag{12}$$

where:
N – normal force [kN],
A – cross area of sample [m^2].

The shear stress τ in kPa at discretionary shear moment is calculated by the formula:

$$\tau = \frac{T}{A} \tag{13}$$

where T – shear force (force against shearing) [kN].

The values of tgφ and c are obtained from the formulae:

$$\text{tg}\,\varphi = \frac{1}{a}\left(n\sum\tau\sigma_{eff} - \sum\tau\sum\sigma_{eff}\right), \tag{14}$$

$$c = \frac{1}{a}\left(\sum\tau\sum\sigma_{eff}^2 - \sum\sigma_{eff}\sum\tau\sigma_{eff}\right), \tag{15}$$

where τ and σ_{eff} expressed in kPa are the pair of stresses obtained for each specimen and n is the number of specimens.

$$a = n\sum \sigma_{eff}^2 - \left(\sum \sigma_{eff}\right)^2. \tag{16}$$

Note that the number of addends in summation symbol is equal to the number of specimens.

The parameters φ and c correspond to the peak shear strength (φ_{eff}, c_{eff}) or residual shear strength (φ_r, c_r) depending on whether the values of $\tau_{\max}$ or $\tau_{\min}$ have been used.

As we can see, PN-88/B-04481 takes into account the influence of shear area changing when calculating shear stress (see formulae (6) and (7)), whereas ETC5-F2.97 and STN 73 1030 do not. We can expect that the result of shear stress calculation, with the shear area being reduced, will be higher, giving higher values of shear strength parameters. The influence of shear area changing on the shear strength parameters of soils will be shown in section 6.

4. INFLUENCE OF CONVENTIONAL TEST ENDING LINEAR DEFORMATION

As mentioned in the previous sections, in accordance with ETC5-F2.97, the test can be terminated when the strain at peak load is clearly exceeded or when the horizontal displacement has reached 20% of the diameter or the width of the specimen. By PN-88/B-04481, in the case where in three subsequent readings the shear force remains constant or decreases, the test is stopped, otherwise the shearing has to continue until the shear displacement reaches linear deformation $\varepsilon = 10\%$. As stated in STN 73 1030, specimen is sheared until shear displacement reaches one tenth of its size (specimen diameter or side).

Therefore, if no peak shear stress is reached, PN-88/B-04481 and STN 73 1030 take values of shear stress at linear deformation $\varepsilon = 10\%$ to calculate shear strength parameters, while ETC5-F2.97 takes values of shear stress at linear deformation up to $\varepsilon = 20\%$ (it can be equal to but also it can be higher than shear stress at linear deformation $\varepsilon = 10\%$), so shear strength parameters calculated by ETC5-F2.97 can be higher. The results are shown in section 6.

5. INFLUENCE OF THE NUMBER OF SPECIMENS

By ETC5-F2.97, normally three similar specimens should be prepared from an undisturbed or reconstituted cohesive sample, for testing under three different normal stresses. Non-cohesive samples should be large enough to provide three separate specimens, so as to avoid having to re-use the same material. ETC5-F2.97 does not specify how to exclude the same specimen from evaluation.

By PN-88/B-04481, it is necessary to calculate the values of soil shear strength parameters by the least squares method using at least five specimens. As was mentioned (see section 3), according to PN-88/B-04481 one should check whether the deviation of point (σ, τ_f) is more than 25% of the value of τ_f. If yes, it is necessary to exclude that particular specimen from evaluation and use the next one to ensure that the conditions are fulfilled.

By STN 73 1030, for the test of peak strength, at least four specimens of the same physical properties are to be prepared; the test of residual shear strength is carried out on at least three different normal stresses (i.e., at least three specimens).

By STN 73 1030, close-fittingness of equivalent shear strength line by linear regression between σ_{eff} and τ at every straight line section is checked by comparing the selected correlation coefficient r and critical values of this coefficient r_a. The selected correlation coefficient r is calculated by the formula:

$$r = \frac{n\sum(\tau\sigma_{eff}) - \sum\tau\sum\sigma_{eff}}{\sqrt{a\left[n\sum\tau^2 - \left(\sum\tau\right)^2\right]}}. \tag{17}$$

The value of r_a can be found from table 4 of the standard (e.g., for $n = 4$ and chosen significance level 0.05, $r_a = 0.95000$; and for $n = 5$ and chosen significance level 0.01, $r_a = 0.95873$). The equivalent shear strength line is accepted if $r \geq r_a$. In the case of $r < r_a$ it is necessary to verify whether there is any reason to exclude some specimen from evaluation. If after verification the condition $r \geq r_a$ is still not fulfilled, it is necessary to find another fit line, which would better fit the effective shear strength. Usually, a multirefracted line is sufficient.

Obviously, the shear strength parameters will vary depending on whether these are evaluated using 3, 4 or 5 specimens. The results are shown in section 6.

6. EXAMPLE

To evaluate the influence of the aforementioned factors on the values of shear strength parameters, tests were performed on kaolin (from ceramic factory in Tułowice, Poland) and natural soil (from Niepołomice, Poland). The kaolin was classified by USCS as CI with $w = 25.37\%$, $w_L = 39.72\%$, $w_p = 21.15\%$; natural soil was classified as CE with $w = 61.02\%$, $w_L = 127.90\%$, $w_p = 45.02\%$. Test conditions were chosen so as to satisfy the requirements of all the documents in this respect. In the tests under consideration, the parameters of residual shear strength were not evaluated. The size of specimens was 60 mm × 60 mm × 15 mm, the time of consolidation was 4 hours and shear speeds were 0.01 mm/min (slow test) and 1mm/min (quick test). The specimens were tested under normal stresses of 50 kPa, 100 kPa, 200 kPa, 300 kPa and 400 kPa (marked as specimen number 1, 2, 3, 4, 5).

Table 1

The values of shear stress for slow and quick tests and values of shear strength parameters obtained for five specimens

Normal stress σ [kPa] and strength parameters	Values of τ [kPa] for kaolin (CI), Tułowice, Poland						Values of τ [kPa] for clay (CE), Niepołomice, Poland					
	Slow test (0.01 mm/min)			Quick test (1 mm/min)			Slow test (0.01 mm/min)			Quick test (1 mm/min)		
	PN	STN	ETC5	PN	STN	ETC5	PN	STN	ETC5	PN	STN	ETC5
50	28.12	26.06	26.06	23.71	22.19	22.19	34.60	33.77	Same values as by STN	35.36	33.47	Same values as by STN
100	52.83	48.10	48.10	36.24	32.61	34.70	56.90	53.67		48.21	44.33	
200	104.06	93.65	93.65	71.52	64.37	68.73	88.30	84.13		70.07	67.85	
300	155.85	143.38	143.38	127.28	114.55	124.43	111.08	104.63		75.66	73.27	
400	194.56	175.11	176.66	152.99	137.69	150.18	146.86	140.52		106.86	103.73	
φ [°]	**25.80**	**23.57**	**23.75**	**21.33**	**19.28**	**20.94**	**17.10**	**16.29**		**10.67**	**10.63**	
c [kPa]	**5.56**	**5.64**	**5.19**	**0.33**	**0.81**	**0.00**	**22.95**	**21.97**		**27.66**	**25.11**	
R^2 [–]	0.99720	0.99513	0.99614	0.98573	0.98499	0.98517	0.99273	0.99212		0.96181	0.96425	

Table 2

Influence of shear speed on the values of shear strength parameters (slow test: 0.01 mm/min; quick test: 1 mm/min)

Type of test	Shear strength parameters of kaolin (CI), Tułowice, Poland						Shear strength parameters of clay (CE), Niepołomice, Poland			
	PN		STN		ETC5		PN		STN, ETC5	
	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]
Slow test	25.80	5.56	23.57	5.64	23.75	5.19	17.10	22.95	16.29	21.97
Quick test	21.33	0.33	19.28	0.81	20.94	0	10.67	27.66	10.63	25.11
Difference [°, kPa]	**4.47**	**5.23**	**4.29**	**4.83**	**2.81**	**5.19**	**6.43**	**–4.71**	**5.66**	**–3.14**
Difference [%]	**17.33**	**94.06**	**18.20**	**85.64**	**11.83**	**100**	**37.60**	**20.52**	**34.75**	**14.29**

The values of shear stresses obtained by the formulae introduced above are given in table 1 (in the tables and figures, instead of the full numbers of the documents, the following abbreviations are used: ETC5, PN and STN). Also, the values of shear strength parameters for five specimens are quoted in table 1. Note that the values of shear strength parameters for kaolin (CI), quick test, acc. to ETC5-F2.97, were originally $\varphi = 21.12°$ and $c = -1.08$ kPa. In the case where cohesion from the test is negative but there is no reason for excluding some specimen from the evaluation, STN 72 1030 recommends puting $c = 0$ kPa and calculating the value of φ by the least squares method with condition of the shear strength line passing the initial point of coordinate system. In that case, $\varphi = 20.94°$ (for comparison purposes, such a procedure will not be applied when analyzing the influence of the number of specimens on the values of shear strength parameters, see next paragraph).

The influence of shear speed on the values of shear strength parameters is shown in table 2. As we can see, for kaolin (CI), the values of shear strength parameters obtained from the quick test are lower than those obtained from the slow test. Differences in the values of angle of internal friction are from 2.81° to 4.47° (11.83% to 17.33%), depending on the document. For clay (CE), the values of angle of internal friction obtained from the quick test are relatively more lower than those obtained from the slow test, from 5.66° (34.75%) to 6.43° (37.60%) but cohesion is higher, from 3.14 kPa (14.29%) to 4.71 kPa (20.52%). An example of the influence of shear speed on the values of shear strength parameters is shown in figure 1.

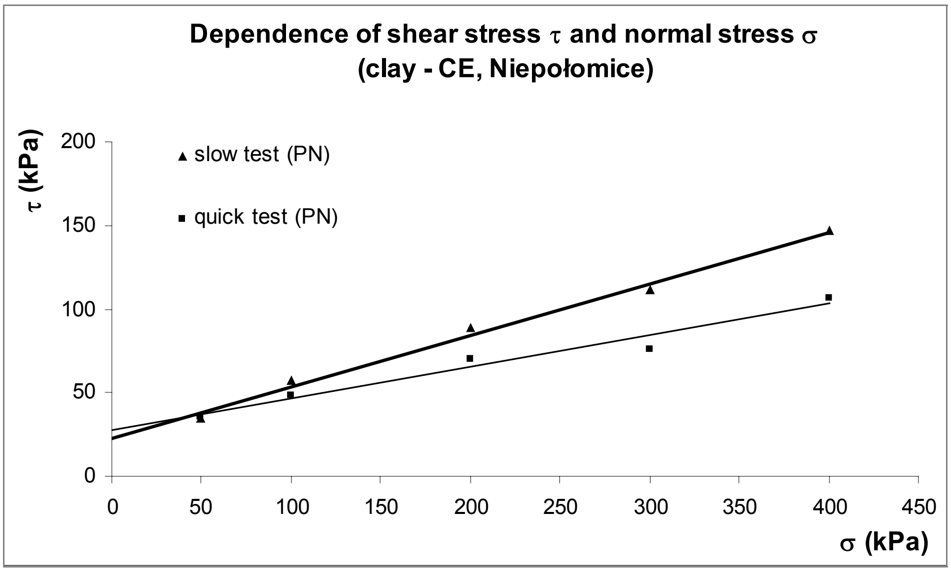

Fig. 1. Influence of shear speed on the values of shear strength parameters, clay (CE), by PN (for slow test $\varphi = 17.10°$, $c = 22.95$ kPa; for quick test $\varphi = 10.67°$, $c = 27.66$ kPa)

Table 3

Influence of shear area changing on the values of shear strength parameters (by PN: changing shear area, by STN: constant shear area)

	Shear strength parameters of kaolin (CI), Tułowice, Poland				Shear strength parameters of clay (CE), Niepołomice, Poland			
	Slow test (0.01 mm/min)		Quick test (1 mm/min)		Slow test (0.01 mm/min)		Quick test (1 mm/min)	
	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]
PN	25.80	5.56	21.33	0.33	17.11	22.95	10.67	27.66
STN	23.57	5.64	19.28	0.81	16.29	21.97	10.63	25.11
Difference [°, kPa]	**2.23**	**–0.08**	**2.05**	**–0.48**	**0.82**	**0.98**	**0.04**	**2.55**
Difference [%]	**8.64**	**1.44**	**9.61**	**145.45**	**4.79**	**4.27**	**0.37**	**9.22**

Table 4

Influence of conventional test ending linear deformation on the values of shear strength parameters
(by ETC5: conventional ending linear deformation $\varepsilon = 15\%$; by STN: conventional ending linear deformation $\varepsilon = 10\%$)

	Shear strength parameters of kaolin (CI), Tułowice, Poland				Shear strength parameters of clay (CE), Niepołomice, Poland			
	Slow test (0.01 mm/min)		Quick test (1 mm/min)		Slow test (0.01 mm/min)		Quick test (1 mm/min)	
	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]
ETC5	23.75	5.19	20.94	0	16.29	21.97	10.63	25.11
STN	23.57	5.64	19.28	0.81	16.29	21.97	10.63	25.11
Difference [°, kPa]	**0.18**	**–0.45**	**1.66**	**0.81**	**0.00**	**0.00**	**0.00**	**0.00**
Difference [%]	**0.76**	**8.67**	**7.93**	**–**	**0.00**	**0.00**	**0.00**	**0.00**

The influence of shear area changing on the values of shear strength parameters is shown in table 3. As we can see, for kaolin (CI), the values of an angle of internal friction obtained when taking into account the shear area changing (as by PN-88/B-04481) is higher compared to the case where the shear area changing is not accounted for (by STN 73 1030); for the slow test, the difference is 2.23° (8.64%); for the quick test, the difference is 2.05° (9.61%). There is a very small difference in the values of cohesion. For clay (CE), due to the fact that the peak shear stresses have been reached at relatively small shear deformations, there is no considerable difference in the origin shear area and shear area at peak shear stress, so the differences are not so big (as regards the values of an angle of internal friction these are from 0.04° (0.37%) to 0.82° (4.79%)). A little bigger is the difference in cohesion for the quick test, 2.55 kPa (9.22%). An example of the influence of shear area changing on the values of shear strength parameters is shown in figure 2.

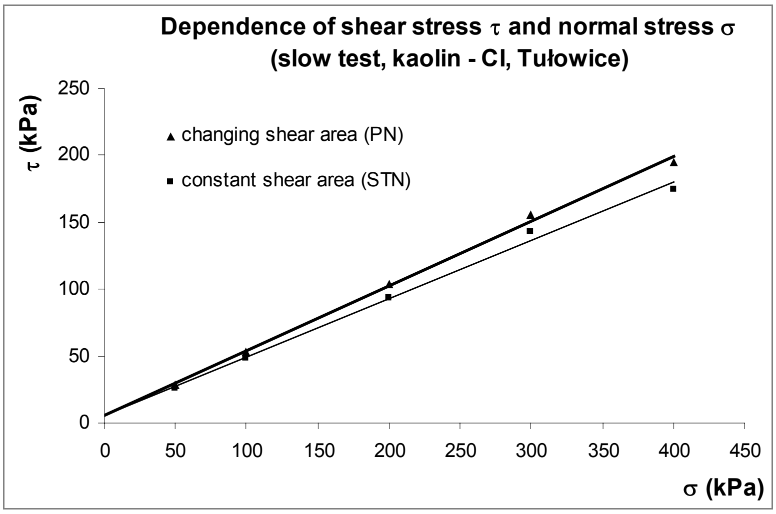

Fig. 2. Influence of shear area changing on the values of shear strength parameters, slow test, kaolin (CI); by PN (changing shear area: $\varphi = 25.80°$, $c = 5.56$ kPa); by STN (constant shear area: $\varphi = 23.57°$, $c = 5.64$ kPa)

The influence of conventional test ending linear deformation ($\varepsilon = 10\%$ or 15%) on the values of shear strength parameters is shown in table 4. We would like to note that since the wall thickness of the apparatus is only 11 mm, less than 12 mm, corresponding with $\varepsilon = 20\%$, the value $\varepsilon = 15\%$ was taken as ending linear deformation by ETC5-F2.97. As we can see, for kaolin (CI), in the slow test, the differences are small (compare STN 72 1030 and ETC5-F2.97), as there is the shear stress difference in one specimen only (see table 1, shear stresses at normal stress 400 kPa). In the case of the quick test, the difference is greater, since there are shear stress differences in four specimens, except for shear stress at normal stress 50 kPa (see also table 1). For clay

(CE), the conventional test ending linear deformation has no influence on the values of shear strength parameters. An example of the influence of test ending linear deformation on the values of shear strength parameters is shown in figure 3.

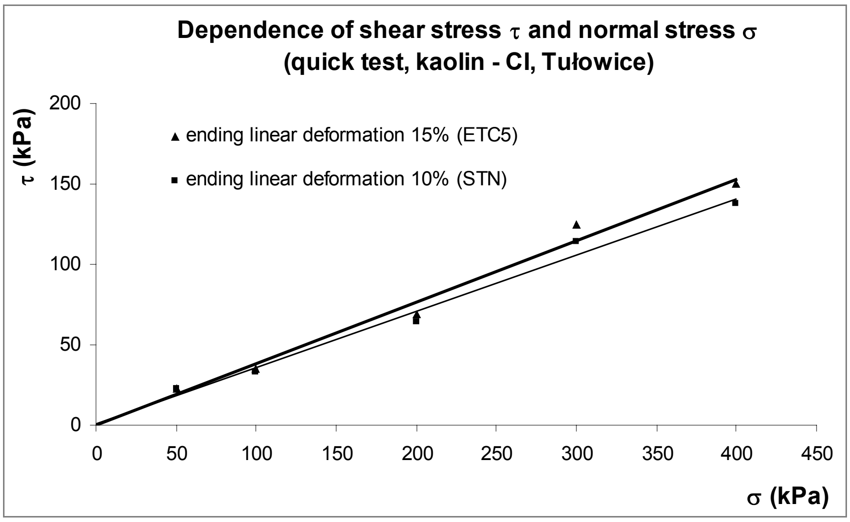

Fig. 3. Influence of test ending linear deformation on the values of shear strength parameters, quick test, kaolin (CI); by ETC5 (ending linear deformation $\varepsilon = 15\%$: $\varphi = 20.94°$, $c = 0$ kPa); by STN (ending linear deformation $\varepsilon = 10\%$: $\varphi = 19.28°$, $c = 0.81$ kPa)

The influence of the number of specimens on the values of shear strength parameters is shown in tables 5 and 6 (for kaolin, CI) and tables 7 and 8 (for clay, CE). Combinations of 3 specimens have been made following ETC5-F2.97, combinations of 4 specimens have been made following STN 72 1030. By PN-88/B-04481, it is necessary to evaluate 5 specimens. As we can see, the values of shear strength parameters strongly depend on the fact of whether they are evaluated using 3, 4 or 5 specimens.

The differences in the values of kaolin (CI) shear strength parameters (slow test), evaluated with a combination of 3 specimens and 4 specimens, where the extreme (maximum) value of internal angle of friction and cohesion has been reached, are given in table 9.

So, for example, when taking a combination of 3 specimens, the combination of specimens with order number 2, 3 and 4 (under normal stresses 100 kPa, 200 kPa and 300 kPa) gives $\varphi = 27.5°$ (max φ) and $c = 1.24$ kPa (see also table 5), while the combination of specimens with order number 3, 4 and 5 (under normal stresses 200 kPa, 300 kPa and 400 kPa) gives $\varphi = 24.35°$ and $c = 15.73$ kPa (max c). The differences are $\Delta\varphi = 2.9°$ (10.64%) and $\Delta c = -14.49$ kPa (1168.55%). This example shows that for the same interval of normal stresses from 200 kPa to 300 kPa, there are two valid couples of values of shear strength parameters, which differ from one another, depending on the combination of specimens.

T a b l e 5

The values of kaolin (CI) shear strength parameters obtained by slow test, evaluated by various combinations of specimens

Test by	Parameters	Values of kaolin (CI) shear strength parameters evaluated by combination of 3 specimens (numbers in the heads of column are order numbers of specimens) – **slow test**										Max (φ) (3 specim.)	Max (c) (3 specim.)
		1,2,3	1,2,4	1,2,5	1,3,4	1,3,5	1,4,5	*2,3,4*	2,3,5	2,4,5	*3,4,5*	*2,3,4*	*3,4,5*
PN	φ [°]	26.89	27.12	25.38	27.05	25.38	25.75	*27.25*	25.15	25.57	*24.35*	**27.25**	**24.35**
	c [kPa]	2.51	2.12	4.85	2.41	6.15	5.59	*1.24*	7.58	6.18	*15.73*	**1.24**	**15.73**
	R^2 [–]	0.99992	0.99995	0.99997	0.99996	0,99899	0.99677	0.99999	0.99901	0.99565	0.99310	0.99999	0.99310
STN	φ [°]	24.29	25.23	23.02	25.07	23.02	23.47	*25.47*	22.83	23.31	*22.16*	**25.47**	**22.16**
	c [kPa]	3.29	1.82	5.18	1.94	6.23	6.30	*–0.24*	7.37	7.28	*15.20*	**-0.24**	**15.20**
	R^2 [–]	0.99993	0.99984	0.99998	0.99926	0.99918	0.99400	0.99936	0.99920	0.99172	0.98399	0.99936	0.98399
ETC5	φ [°]	24.29	25.23	23.25	25.07	23.24	23.64	*25.74*	23.10	23.53	*22.54*	**25.74**	**22.54**
	c [kPa]	3.29	1.82	4.83	1.94	5.74	5.92	*–0.24*	6.59	6.61	*13.38*	**–0.24**	**13.38**
	R^2 [–]	0.99993	0.99984	0.99999	0.99926	0.99946	0.99524	0.99936	0.99945	0.99339	0.98710	0.99936	0.98710

Test by	Parameters	Values of kaolin (CI) shear strength parameters evaluated by combination of 4 specimens (numbers in the heads of column are order numbers of specimens) – **slow test**					Max (φ) (4 specimens)	Max (c) (4 specimens)	Max (φ) (all combinations)	Max (c) (all combinations)	**φ and c (5 specimens)**
		1,2,3,4	1,2,3,5	1,2,4,5	1,3,4,5	*2,3,4,5*	*1,2,3,4*	*2,3,4,5*	*2,3,4*	*3,4,5*	*1,2,3,4,5*
PN	φ [°]	*27.09*	25.42	25.81	25.70	*25.50*	**27.09**	**25.50**	**27.25**	**24.35**	**25.80**
	c [kPa]	*2.08*	5.79	5.05	6.35	*7.58*	**2.08**	**7.58**	**1.24**	**15.73**	**5.56**
	R^2 [–]	0.99994	0.99911	0.99741	0.99665	0.99576	0.99994	0.99576	0.99999	0.99310	0.99720
STN	φ [°]	*25.12*	23.05	23.58	23.46	*23.30*	**25.12**	**23.30**	**25. 47**	**22.16**	**23.57**
	c [kPa]	*1.61*	5.93	5.42	6.50	*7.37*	**1.61**	**7.37**	**–0.24**	**15.20**	**5.64**
	R^2 [–]	0.99933	0.99928	0.99518	0.99414	0.99226	0.99933	0.99226	0.99936	0.98399	0.99513
ETC5	φ [°]	*25.12*	23.28	23.75	23.64	*23.53*	**25.12**	**23.53**	**25.47**	**22.54**	**23.75**
	c [kPa]	*1.61*	5.46	5.05	5.99	*6.59*	**1.61**	**6.59**	**–0.24**	**13.38**	**5.19**
	R^2 [–]	0.99933	0.99952	0.99616	0.99537	0.99383	0.99933	0.99383	0.99936	0.98710	0.99614

Table 6

The values of kaolin (CI) shear strength parameters obtained by quick test, evaluated by various combinations of specimens

Test by	Parameters	Values of kaolin (CI) shear strength parameters evaluated by combination of 3 specimens (numbers in the heads of column are order numbers of specimens) – **quick test**										Max (φ) (3 specim.)	Max (c) (3 specim.)
		1,2,3	1,2,4	1,2,5	1,3,4	1,3,5	*1,4,5*	*2,3,4*	2,3,5	2,4,5	3,4,5	*2,3,4*	*1,4,5*
PN	φ [°]	17.93	23.07	20.62	22.13	20.38	*20.71*	*24.48*	21.39	21.73	22.16	**24.48**	**20.71**
	c [kPa]	6.07	–1.48	2.00	–0.39	2.27	*6.83*	*–12.69*	–4.49	–0.79	–4.94	**–12.96**	**6.83**
	R^2 [–]	0.99391	0.99375	0.99802	0.97485	0.99553	0.99155	0.98342	0.99882	0.98510	0.95661	0.98342	0.99155
STN	φ [°]	15.98	20.85	18.63	19.92	18.36	*18.65*	*22.28*	19.42	19.73	20.13	**22.38**	**18.65**
	c [kPa]	6.32	–0.69	2.37	0.59	2.82	*7.08*	*–11.43*	–4.05	–0.71	–4.44	**–11.43**	**7.08**
	R^2 [–]	0.99119	0.99246	0.99742	0.97303	0.99480	0.99182	0.98342	0.99882	0.98510	0.95661	0.98342	0.99182
ETC5	φ [°]	17.46	22.80	20.43	21.86	20.20	*20.51*	*24.16*	21.21	21.51	22.16	**24.16**	**20.51**
	c [kPa]	5.18	–2.60	0.75	–1.76	0.65	*5.43*	*–13.87*	–6.03	–1.98	–7.73	**–13.87**	**5.43**
	R^2 [–]	0.99499	0.99396	0.99809	0.97247	0.99454	0.99198	0.98093	0.99818	0.98579	0.95687	0.98093	0.99198

Test by	Parameters	Values of kaolin (CI) shear strength parameters evaluated by combination of 4 specimens (numbers in the heads of column are order numbers of specimens) – **quick test**					Max (φ) (4 specimens)	Max (c) (4 specimens)	Max (φ) (all combinations)	Max (c) (all combinations)	**φ and c (5 specimens)**
		1,2,3,4	1,2,3,5	1,2,4,5	*1,3,4,5*	2,3,4,5	*1,2,3,4*	*1,3,4,5*	*2,3,4*	*1,4,5*	*1,2,3,4,5*
PN	φ [°]	*22.47*	20.57	21.28	*21.01*	22.10	**22.47**	**21.01**	**24.48**	**20.71**	**21.33**
	c [kPa]	*–2.52*	0.75	2.28	*2.65*	–4.49	**–2.52**	**2.65**	**–12.96**	**6.83**	**0.33**
	R^2 [–]	0.97743	0.99560	0.99035	0.98346	0.98206	0.97743	0.98346	0.98342	0.99155	0.98573
STN	φ [°]	*20.29*	18.58	19.23	*18.95*	20.07	**20.29**	**18.95**	**22.38**	**18.45**	**19.28**
	c [kPa]	*–1.63*	1.20	2.63	*3.16*	–4.05	**–1.63**	**3.16**	**–11.43**	**7.08**	**0.81**
	R^2 [–]	0.97545	0.99474	0.98993	0.98287	0.98206	0.97545	0.98287	0.98342	0.99182	0.98499
ETC5	φ [°]	*22.16*	20.37	21.07	*20.83*	21.91	**22.16**	**20.83**	**24.16**	**20.51**	**21.12**
	c [kPa]	*–3.68*	–0.66	1.02	*1.03*	–6.03	**–3.68**	**1.03**	**–13.87**	**5.43**	**–1.08**
	R^2 [–]	0.97563	0.99491	0.99079	0.98274	0.98174	0.97563	0.98274	0.98093	0.99198	0.98530

Table 7

The values of clay (CE) shear strength parameters obtained by slow test, evaluated by various combinations of specimens

Test by	Parameters	Values of clay (CE) shear strength parameters evaluated by combination of 3 specimens (numbers in the heads of column are order numbers of specimens) – **slow test**										Max (φ) (3 specim.)	Max (c) (3 specim.)
		1,2,3	1,2,4	1,2,5	1,3,4	1,3,5	1,4,5	*2,3,4*	2,3,5	2,4,5	3,4,5	*1,2,3*	*2,3,4*
PN	φ [°]	*19.38*	16.49	17.40	17.23	17.70	17.64	*15.16*	16.64	16.47	16.32	**19.38**	**15.16**
	c [kPa]	*18.90*	23.14	21.99	21.15	20.75	18.04	*31.25*	27.63	26.09	27.59	**18.90**	**31.25**
	R^2 [–]	0.99144	0.99055	0.99683	0.98697	0.99671	0.99869	0.99163	0.99969	0.99475	0.98385	0.99144	0.99163
STN	φ [°]	*18.33*	15.39	16.68	16.04	16.90	16.74	*14.29*	16.09	15.88	15.75	**18.33**	**14.29**
	c [kPa]	*18.54*	22.74	21.70	21.46	20.33	17.76	*29.85*	25.48	23.74	25.18	**18.54**	**29.85**
	R^2 [–]	0.99515	0.99268	0.99809	0.98479	0.99753	0.99691	0.98745	0.99962	0.99188	0.97581	0.99515	0.98745
ETC5	φ [°]	Results are the same as by STN											
	c [kPa]												
	R^2 [–]												

Test by	Parameters	Values of clay (CE) shear strength parameters evaluated by combination of 4 specimens (numbers in the heads of column are order numbers of specimens) – **slow test**					Max (φ) (4 specimens)	Max (c) (4 specimens)	Max (φ) (all combinations)	Max (c) (all combinations)	**φ and c (5 specimens)**
		1,2,3,4	*1,2,3,5*	1,2,4,5	1,3,4,5	*2,3,4,5*	*1,2,3,5*	*2,3,4,5*	*1,2,3*	*2,3,4*	*1,2,3,4,5*
PN	φ [°]	16.81	*17.44*	17.13	17.44	*16.31*	**17.44**	**16.31**	**19.38**	**15.16**	**17.10**
	c [kPa]	23.64	*22.77*	21.87	20.60	*27.63*	**22.77**	**27.63**	**18.90**	**31.25**	**22.95**
	R^2 [–]	0.98400	0.99547	0.99509	0.99380	0.99347	0.99547	0.99347	0.99144	0.99163	0.99273
STN	φ [°]	15.73	*16.71*	16.32	16.56	*15.70*	**16.71**	**15.70**	**18.33**	**14.29**	**16.29**
	c [kPa]	23.27	*21.75*	20.92	20.14	*25.48*	**21.75**	**25.48**	**18.54**	**29.85**	**21.97**
	R^2 [–]	0.98381	0.99696	0.99456	0.99225	0.99011	0.99696	0.99011	0.99515	0.98745	0.99212
ETC5	φ [°]	Results are the same as by STN									
	c [kPa]										
	R^2 [–]										

Table 8

The values of clay (CE) shear strength parameters obtained by quick test, evaluated by various combinations of specimens

Test by	Parameters	Values of clay (CE) shear strength parameters evaluated by combination of 3 specimens (numbers in the heads of column are order numbers of specimen) – **quick test**										Max (φ) (3 specim.)	Max (c) (3 specim.)
		1,2,3	1,2,4	1,2,5	1,3,4	1,3,5	1,4,5	*2,3,4*	2,3,5	2,4,5	3,4,5	*1,2,3*	*2,3,4*
PN	φ [°]	*12.93*	8.78	11.38	9.47	11.49	11.09	*7.82*	10.97	10.60	10.42	**12.93**	**7.82**
	c [kPa]	*24.43*	29.92	26.58	29.79	26.74	23.63	*37.19*	29.81	26.99	29.01	**24.43**	**37.19**
	R^2 [–]	0.99830	0.98389	0.99864	0.92347	0.99571	0.97164	0.89513	0.99804	0.94935	0.86092	0.99830	0.89513
STN	φ [°]	*12.95*	8.82	11.30	9.35	11.29	10.91	*8.24*	11.05	10.78	10.17	**12.95**	**8.24**
	c [kPa]	*21.71*	27.10	23.88	28.00	25.11	21.97	*32.87*	26.38	23.00	27.79	**21.71**	**32.87**
	R^2 [–]	0.99962	0.99410	0.99987	0.92225	0.99512	0.97273	0.88479	0.99503	0.95865	0.86047	0.99962	0.88479
ETC5	φ [°]	Results are the same as by STN											
	c [kPa]												
	R^2 [–]												

Test by	Parameters	Values of clay (CE) shear strength parameters evaluated by combination of 4 specimens (numbers in the heads of column are order numbers of specimens) – **quick test**					Max (φ) (4 specimens)	Max (c) (4 specimens)	Max (φ) (all combinations)	Max (c) (all combinations)	**φ and c (5 specimens)**
		1,2,3,4	*1,2,3,5*	1,2,4,5	1,3,4,5	2,3,4,5	*1,2,3,5*	*1,2,3,4*	*1,2,3*	*2,3,4*	*1,2,3,4,5*
PN	φ [°]	*9.30*	*11.41*	10.71	10.87	10.29	**11.41**	**9.30**	**12.93**	**7.82**	**10.67**
	c [kPa]	*30.71*	*27.29*	26.33	26.40	29.81	**27.29**	**30.71**	**24.43**	**37.19**	**27.66**
	R^2 [–]	0.92960	0.99598	0.97095	0.95683	0.93769	0.99598	0.92960	0.99830	0.89513	0.96181
STN	φ [°]	*9.37*	*11.34*	10.68	10.68	10.41	**11.34**	**9.37**	**12.95**	**8.24**	**10.63**
	c [kPa]	*27.92*	*24.75*	23.64	24.70	26.38	**24.75**	**27.92**	**21.71**	**32.87**	**25.11**
	R^2 [–]	0.93267	0.99573	0.97541	0.97504	0.94138	0.99573	0.93267	0.99962	0.88479	0.96425
ETC5	φ [°]	Results are the same as by STN									
	c [kPa]										
	R^2 [–]										

Table 9

The differences of values of kaolin (CI) shear strength parameters, evaluated by various combinations of specimens, slow test

	Combination of 3 specimens						Combination of 4 specimens					
	PN		STN		ETC5		PN		STN		ETC5	
	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]
Max (φ)	27.25	1.24	25.47	–0.24	25.74	–0.24	27.09	2.08	25.12	1.61	25.12	1.61
Max (c)	24.35	15.73	22.16	15.20	22.54	13.38	25.50	7.58	23.30	7.37	23.53	6.59
Difference [°, kPa]	**2.90**	**–14.49**	**3.31**	**–15.40**	**3.20**	**–13.62**	**1.59**	**–5.50**	**1.82**	**–5.76**	**1.59**	**–4.98**
Difference [%]	**10.64**	**1168.55**	**13.00**	**6433.33**	**12.43**	**5675.00**	**5.87**	**264.42**	**7.25**	**357.76**	**6.33**	**309.32**

Table 10

The differences of values of kaolin (CI) shear strength parameters, evaluated by various combinations of specimens, quick test

	Combination of 3 specimens						Combination of 4 specimens					
	PN		STN		ETC5		PN		STN		ETC5	
	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]
Max (φ)	24.48	–12.96	22.38	–11.43	24.16	–13.87	22.47	–2.52	20.29	–1.63	22.16	–3.68
Max (c)	20.71	6.83	18.65	7.08	20.51	5.43	21.01	2.65	18.95	3.16	20.83	1.03
Difference [°, kPa]	**3.77**	**–19.79**	**3.73**	**–18.51**	**3.65**	**–19.30**	**1.46**	**–5.17**	**1.34**	**–4.79**	**1.33**	**–4.71**
Difference [%]	**15.40**	**152.70**	**16.67**	**161.94**	**15.11**	**139.15**	**6.50**	**205.16**	**6.60**	**293.87**	**6.00**	**127.99**

Table 11

The differences of values of clay (CE) shear strength parameters, evaluated by various combinations of specimens, slow test

	Combination of 3 specimens						Combination of 4 specimens					
	PN		STN		ETC5		PN		STN		ETC5	
	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]
Max (φ)	19.38	18.90	18.33	18.54	18.33	18.54	17.44	22.77	16.71	21.75	16.71	21.75
Max (c)	15.16	31.25	14.29	29.85	14.29	29.85	16.31	27.63	15.70	25.48	15.70	25.48
Difference [°, kPa]	**4.22**	**–12.35**	**4.04**	**–11.31**	**4.04**	**–11.31**	**1.13**	**–4.86**	**1.01**	**–3.73**	**1.01**	**–3.73**
Difference [%]	**21.78**	**65.34**	**22.04**	**61.00**	**22.04**	**61.00**	**6.48**	**21.34**	**6.04**	**17.15**	**6.04**	**17.15**

Table 12

The differences of values of clay (CE) shear strength parameters, evaluated by various combinations of specimens, quick test

	Combination of 3 specimens						Combination of 4 specimens					
	PN		STN		ETC5		PN		STN		ETC5	
	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]	φ [°]	c [kPa]
Max (φ)	12.93	24.43	12.95	21.71	12.95	21.71	11.41	27.29	11.34	24.75	11.34	24.75
Max (c)	7.82	37.19	8.24	32.87	8.24	32.87	9.30	30.71	9.37	27.92	9.37	27.92
Difference [°, kPa]	**5.11**	**–12.76**	**4.71**	**–11.16**	**4.71**	**–11.16**	**2.11**	**–3.42**	**1.97**	**–3.17**	**1.97**	**–3.17**
Difference [%]	**39.52**	**52.23**	**36.37**	**51.40**	**36.37**	**51.40**	**18.49**	**12.53**	**17.37**	**12.81**	**17.37**	**12.81**

A similar example is for clay (CE), slow test. The combination of specimens with order number 1,2 and 3 (under normal stresses 50 kPa, 100 kPa and 200 kPa) gives $\varphi = 19.38°$ (max φ) and c = 18.90 kPa (see table 7), while the combination of specimens with order number 2, 3 and 4 (under normal stresses 100 kPa, 200 kPa and 300 kPa) gives $\varphi = 15.16°$ and c = 31.25 kPa (max c), see also table 7. The differences are presented in table 11, where we can see $\Delta\varphi = 4.22°$ (21.78%) and $\Delta c = -12.35$ kPa (65.34%). It means that for the interval of normal stresses from 100 kPa to 200 kPa, we can use both of the two valid couples of values of shear strength parameters, which differ from one another. Such a difference induces difference in the result of calculation, e.g., of bearing capacity, earth pressure or slope stability when building structure in such soil. An example of the influence of the number of specimens on the values of shear strength parameters can be found in figure 4.

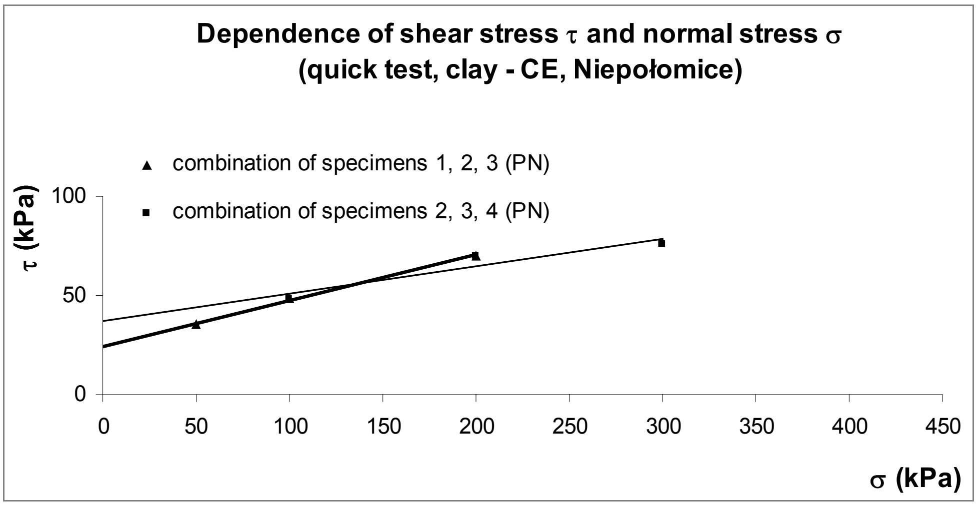

Fig. 4. Influence of the number of specimens on the values of shear strength parameters, quick test, clay (CE); by PN (a combination of specimens with order number 1, 2, 3: $\varphi = 12.93°$, c = 24.33 kPa; a combination of specimens with order number 2, 3, 4: $\varphi = 7.82°$, c = 37.19 kPa)

More about the differences in the values of shear strength parameters of kaolin (CI) and clay (CE), depending on the combination of specimens can be found in tables 9 and 10, and tables 11 and 12. As we can see, the combinations of 4 specimens show smaller differences, since they are more representative. The most representative values of shear strength parameters are in the last column of tables 5, 6, 7 and 8, resulting from the combination of 5 specimens (by PN-88/B-04481).

7. CONCLUSIONS

➢ The values of the shear strength parameters of soil obtained from direct shear test depend on many factors, such as shear speed, shear area changing, conventional test ending linear deformation as well as the number of specimens being tested.

➢ Different shear speeds induce different values of shear strength parameters. For kaolin (CI), the values of shear strength parameters obtained from the quick test (1 mm/min) are lower than those obtained from the slow test (0.01 mm/min). The differences in the values of an angle of internal friction are from 2.81° to 4.47° (11.83% to 17.33%), depending on the document according to which the tests have been carried out. For clay (CE), the values of an angle of internal friction obtained from the quick test are relatively more lower than those obtained from the slow test, from 5.66° to 6.43° (34.75% to 37.60%) but cohesion is higher, from 3.14 kPa to 4.71 kPa (14.29% to 20.52%).

➢ The influence of shear area changing is considered in PN-88/B-04481, but not in STN 72 1030 and ETC5-F2.97. For kaolin (CI), the values of an angle of internal friction obtained when taking into account the shear area changing (as by PN) are higher than in the case where it is not account for (by STN); for the slow test, the difference is 2.23° (8.64%); for the quick test, the difference is 2.05° (9.61%). There is a very small difference in the values of cohesion.

➢ In the case where the peak shear stresses have been reached at relatively small shear deformations, the influence of shear area changing is negligible (because there is no big difference in the origin shear area and shear area at peak shear stress). It is the case of clay (CE), where differences in the values of an angle of internal friction are only from 0.04° to 0.82° (0.37% to 4.79%). A little bigger is the difference in cohesion for the quick test, 2.55 kPa (9.22%).

➢ In our case, the influence of conventional test ending linear deformation on the values of shear strength parameters is small for kaolin (CI). For clay (CE), the conventional test ending linear deformation has no influence on the values of shear strength parameters. In spite of this, attention should be paid when choosing values of linear deformations to calculate shear stresses for the cases where no peak shear strength is reached. The choice has to reflect the actual practical task. Literature recommends shear stresses for linear deformations to calculate between $\varepsilon = 10\%$ and $\varepsilon = 20\%$.

➢ The number of specimens based on which the test result is valuated has the greatest influence on the values of shear strength parameters. In our examples, the maximum differences in the values of shear strength parameters for the interval of normal stresses from 100 kPa to 200 kPa was reached for clay (CE), quick test, taking into account combinations of 3 specimens tested under 50 kPa, 100 kPa, 200 kPa and under 100 kPa, 200 kPa and 300 kPa, where $\Delta\varphi = 5.11°$ (39.52%) and $\Delta c = -12.76$ kPa (52.23%). We recommend to evaluate the values of shear strength parameters from at least 5 specimens as PN-88/B-04481 prescribes.

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