THE TEST OF STRENGTH PROPERTIES OF THE SOIL MEDIUM IN THE COMBINED STATE OF STRESS

Witold Bojanowski

Technical University, Łódź

INTRODUCTION

The investigation of mechanical properties of a building site subsoil, which is composed mainly of granular material, are made in most cases in axial-symmetrical state of stress $\sigma_1 > \sigma_2 = \sigma_3$. This is the only defined space state of stress occuring in the soil sample placed in the triaxial compressing apparatus. The results of these tests give us the strength properties of the soil medium in form of an angle of internal friction and the cohesion in case of cohesive soil, or an angle of internal friction in case of loose soil.

The axial-symmetrical state of stress neglects an influence of an intermediate principal stress σ_2 which is equal to the minimum principal stress σ_3. The strength tests of that kind satisfy Coulomb strength theory. Many researchers [4] pioneered this kind of investigations, tried to explain the problem of an influence of σ_2 on soil strength and by that to verify experimentally Coulomb plasticity condition. Athough the paper [4] appeared in 1936 the full development of researches in combined state of stress $\sigma_1 \neq \sigma_2 \neq \sigma_3$ was begun the 60th. Many a new research device [1] have been invented the results confirmed an essential influence of stress σ_2 on the strength of the examined medium. Those results, however, were not utilized in the present day mandatory standards defining strength of building soils. Applying high safety factors ($n = 2.0$) at defining bearing capacity of the soil, indicates a small interest in the correction of Coulomb condition. It seems that the problem of strength increase of a granular medium examined in combined state of stress should, first of all, be applied in the designing of top soil cutting tools.

In spite of advanced researches on defining cutting resistance of top soils we encounter in practice a quick wear up or transgressing the limits.

of strength of cutting tools. One of the reasons of it could be a misevalution of strength of the machined material. The author, therefore, tries to discuss his own and other researchers results of examining strength properties of loose medium in a combined state of stresses.

THE CALCULATION OF CUTTING RESISTANCE BASED ON TOP SOIL STRENGTH

The author, when discussing the method of calculating cutting agricultural tools resistance, has in mind mainly analitical methods in which the distribution of external forces on the working element of a tool is defined. In those methods the calculation of the horizontal cutting force depends on strength of the machined material — top soil. Strength properties of top soil are taken into account in form of an angle of internal friction φ, angle of external friction ϱ or trigonometrical function of those angles. The angle ϱ for a given material of a tool (steel) is the function of the angle φ. The unitary resistance of cutting k_s used in empirical methods obtained experimentally depends on mechanical properties of to soil and they are, therefore, their function so they can be obtained analytically if φ and c are defined experimentally.

There are many methods of calculating of the horizontal force of cutting [8] based on equations of boundary equilibrium between a tool and soil. Mechanical properties of soil are then defined by Coulomb strength condition

$$\tau_n = \sigma_n \cdot \operatorname{tg} \varphi + c. \tag{1}$$

This condition expressed by the principal stress is of form

$$\sin \varphi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3 + 2c \operatorname{ctg} \varphi}. \tag{2}$$

In case of non-cohesive top soils $c = \Theta$ and the equations take the form

$$\tau_n = \sigma_n \cdot \operatorname{tg} \varphi, \tag{3}$$

$$\sin \varphi = \frac{\sigma_1 - \sigma_3}{\sigma_1 + \sigma_3}. \tag{4}$$

The strength tests of soil and top soil, triaxial and direct shear, are fit to this theory. In the engineering practice and treatment of top soil by cutting tool the axial-symmetrical state of stress scarcely occurs.

Cutting elements of agricultural tools are shaped as combined forms. The reaction of medium will be different depending on their position. A tool causes the space stress in the medium which is more complex than the state of axial symmetry. Therefore a basis of designing agricultural cutting tools should be the strength of the examined medium in a state similar to its real behaviour.

SOIL TESTS IN ARBITRARY COMBINED STATE OF STRESS

Any space states of stress $\sigma_1 \neq \sigma_2 \neq \sigma_3$ can be obtained in the apparatus in which the samples of the tested medium have form of cube, cubicoid, light-wall tube or thick-wall tube. In the paper [1] the author described broadly the construction of those apparatus and methods of research tests. The tests where the sample has cubic-shape [5], [6] have the following disadvantages:

1. No possibility of causing the strain at which the soil reaches an established yield.
2. The disturbances of stress state and strain on cube edges.
3. Non-homogenoues strain of surface transmitting loads, resulted from disturbances on the cube edges.

In apparatuses of this kind the main directions of stresses and strains are, as constructonal assumption, in line what makes impossible testing of the changes during loading process. Some of these disadvantages have been removed from the newest types of apparatuses [3]. The above mentioned disadvantages occur only in the principal direction where the strain is nil in apparatus in which the cubicoid sample is tested. In the sample of thick-wall tube type it is impossible to obtain a homogeneous stress state in radial direction, no matter the way the load is applied.

The most homogeneous state of stress is obtained in a sample in form of thin-wall tube. When the tube is loaded with torsion moment we can investigate changes of principal direction of stresses and strains during the loading. A serious defect of this type tests is a complex technology of preparing samples of cohesive soils and wet sands. Measurement of radial strain ε_{rr} is not easy to be done too.

TESTS RESULTS

To illustrate the influence of intermediate principal stress σ_2 on the strength properties of the loose medium there are represented test results by the author [2] and the most recent tests by T. Ramamurthy and P. C. Rawat [7].

The tests done by the author were carried out on samples in form of light-wall tube ($r_w = 65$ mm, $r_z = 75$ mm and $h = 160$ mm) loaded hydrostatically $\sigma_r = p$, by vertical stress σ_z and by torsion moment M_s. Fine sands of grains from 0.5 mm to 1.0 mm of specific gravity $\gamma_s = 2.65$ G/ /cm³ were tested.

Maximum void ratio of the sand $\varepsilon_{max} = 0.725$, minimum $\varepsilon_{min} = 0.538$. The tests were carried out on samples of density $\gamma_{on} = 1.67$ G/cm³ what corresponds the void ratio $\varepsilon = 0.588$. The author performed six tests of triaxial compression $\sigma_1 > \sigma_2 = \sigma_3$, eleven „tension" tests $\sigma_1 = \sigma_2 > \sigma_3$ and twenty five tests loaded with torsion moment $\sigma_1 \neq \sigma_2 \neq \sigma_3$.

In paper [7] the tests were carried out on cube samples of edge measuring $b = 76$ mm places in a modified triaxial apparatus. The construction of the apparatus allowed to make changes of values of principal stresses into two principal directions and to keep a constant value in the third direction. The samples were made from Ottawa sand of effective size 0.43 mm, specific gravity $\gamma_s = 2.66$ G/cm³, maximum void ratio $\varepsilon_{max} = 0.695$ and minimum void ratio $\varepsilon_{min} = 0.486$. There were done six tests of compression $\sigma_1 > \sigma_2 = \sigma_3$, one test of „tension" $\sigma_1 < \sigma_2 = \sigma_3$ and sixteen tests at a moment when the plasticizing of the material existed in any composite state of stress $\sigma_1 \neq \sigma_2 \neq \sigma_3$.

In Fig. 1 there are recorded results of the tests carried out in the both discussed papers. The results are presented in form of dependence of internal friction angle φ on Lode parameter μ. This parameter is of from.

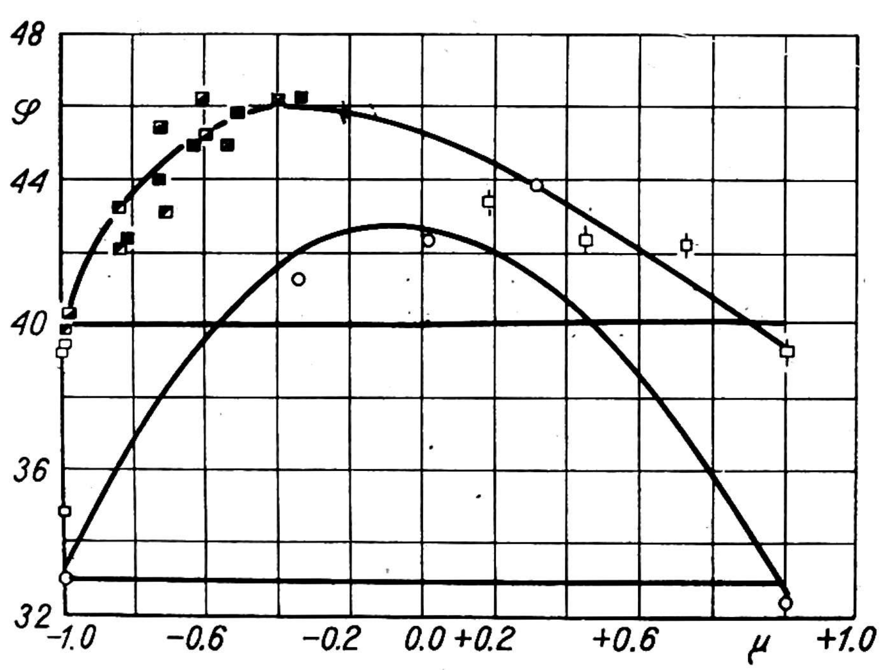

Fig. 1. Internal friction angle versus μ parameter. □ — Ramamurthy's results, ○ — author's results

$$\mu = \frac{2\sigma_2 - \sigma_1 - \sigma_3}{\sigma_1 - \sigma_3} . \quad (5)$$

It describes the situation of the considered state of stress in 1/6 of the pricipal stresses space. The parameter μ varies from —1.0 to + 1.0. All the states of principal stresses situated in the plane of triaxial compression correspond to the value of $\mu = -1.0$, and the states of stresses situated in the plane of triaxial „tension" correspond to the value $\mu = + 1.0$. The points denoted by squares (Fig. 1) are the values of internal friction angle φ; they were obtained in single tests and given in paper [7]. The points denoted by circles are mean value of angle φ; they were obtained in five types of tests (at constant values of μ) carried out by the author. The curves connecting the points are the traces of the plasticity surface of the tested sands. The theoretical trace of Coulomb plasticity condition which is in accordance with the rasults of the triaxial tests, are represented by straight lines of constant value of angle φ independent on parameter μ. For Ottawa sand the straight line corresponds to the angle 40°, for fine sand tested by the author it corresponds to the angle 33°. When we compare the experimental curves with the straight lines of Coulomb it is clearly seen a discrepancy even for the values μ near to the axial symmetry.

The maximum difference occurs when the parameter μ is between the values —0.4 and +0.2. The maximum difference in value of angle

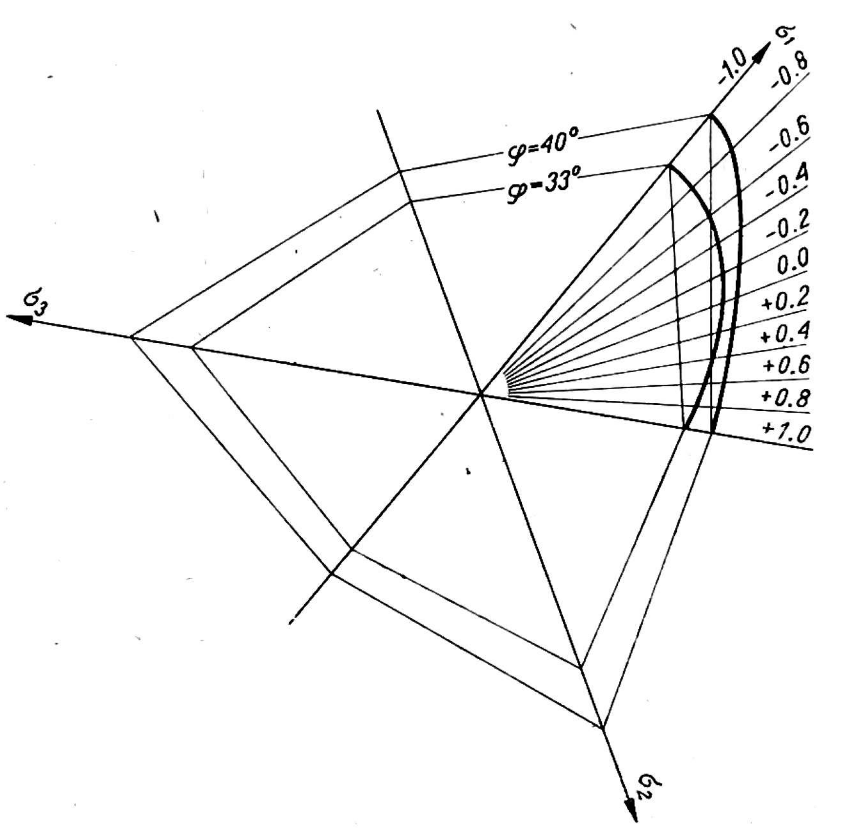

Fig. 2. Plasticity condition on the octaedral plane

φ for Ottawa sand is 6° 30′. It is an increase by 16%. For fine sand the difference is 9° 20′ and the increase reaches 28%. To ilustrate fully the obtained results they are showed in Fig. 2 in the octahedron plane $\sigma_{okt.} = \sigma_{śr} = 1.0$ kG/cm². For the sake of comparision the traces of the spatial form of Coulomb plasticity condition are denoted in the intersection with the octahedron plane. These are the traces for angles $\varphi = 40°$ and $\varphi = 33°$. For the sake of simplification the results of the test are plotted only in 1/6 projection of principal stresses space on the octahedron plane. It is clearly seen here that plasticity conditions of both the soils — obtained experimentally are outside the trace of Coulomb condition. This proves that tests done in accordance with Coulomb condition in samples loaded axialy-symmetric state of stress present a lower strength of the medium than an estimation of the strength in any combined arbitrary states of stress.

CONCLUSIONS

The test results of sand soils carried aut in two different types of apparatus converge. Both the papers [2, 7] confirmed influence of intermediate principal stress $\sigma_2 \neq \sigma_1 \neq \sigma_3$ on an increace of strength of loose medium in comparison with Coulomb plasticity condition.

An increase of strenght of fine sands is expresses by an increase of internal friction angle by 16 to 28 per cent. Such an increase of strength of soil medium should not be neglected at calculations of cutting resistance.

An introducing a new estimation of top soils strength into practical calculations requires doing quantitative tests for different kind of top soils and the establishing the coefficients increasing values of friction angle as it is defined in traditional triaxial measuring apparatus.

REFERENCES

1. Bojanowski W.: O metodach badań gruntów w złożonym stanie naprężenia. Arch. Inż. ląd. z. 1-2, 1969.
2. Bojanowski W.: The Study of the Influence of Intermediate Principal Stress on the strength of Granular Material. Studia Geotechnica. Vol. 1 No. 1, 1970.
3. Golscheider M., Cudehus G.: Rectiliner Extension of Dry Sand: Testing Apparatus and Experimental Results. Proceedings of the Eighth International Conference on Soil Mechanics and Foundation Enginering, Moscow 1973.
4. Kjellman W.: Report on an Apparatus for Consumente Investigation of the Mechanical Properties of Soil. Preceedings of the First Intern. Conf. on Soil Mech. and Found. Eng. Cambridge Mass. 1936.
5. K.O, H.Y, Scott R. F.: Deformation of Sand at Failure. Journ., of the Soil Mech. and Found. Division Vol. 94, SM 4, 1968.

6. Ломизе Г. М. Крыжановский А. Л. Прочность грунтов. Гидромехан. Строит. Ир. 3, 1967.
7. Ramamurthy T., Rawat P. C.: Shear Strength of Sand Under General Stress System. Proceedings of the Eighth Intern. Conf. on Soil Mech. and Found. Eng. Moscow 1973.
8. Zdanowicz A.: Podstawowe problemy mechaniki procesu skrawania gruntów narzędziami rolniczymi. Rocz. Nauk rol. PAN, Seria D, Tom 136.

W. Bojanowski

BADANIA WŁASNOŚCI WYTRZYMAŁOŚCIOWYCH OŚRODKA GRUNTOWEGO W ZAŁOŻONYCH STANACH NAPRĘŻENIA

Streszczenie

Autor opisał badanie gruntów w dowolnie złożonych stanach naprężeń tzn. gdy wszystkie trzy naprężenia główne mają różne wartości. Z wyników badań można wnioskować, że pomiary prowadzone na próbkach obciążonych osiowo symetrycznym naprężeniem dają niższą wytrzymałość ośrodka gruntowego od oceny tej wytrzymałości w dowolnych złożonych stanach naprężenia. Może to być przyczyną szybkiego zużycia lub przekroczenia wytrzymałości narzędzi skrawających glebę.

В. Бояновски

ИССЛЕДОВАНИЯ ОБУСЛАВЛИВАЮЩИХ СОПРОТИВЛЕНИЕ СВОЙСТВ ПОЧВОГРУНТОВОЙ СРЕДЫ В СЛОЖНЫХ СОСТОЯНИЯХ НАПРЯЖЕНИЙ

Резюме

Автор описывает ход исследований почвогрунтов в произвольно сложных состояниях напряжений, т.е. когда все три главные напряжения имеют разные величины. Результаты исследований позволяют заключать, что измерения проводимые на образцах с нагрузкой осево-симетрического напряжения показывают заниженное сопротивление почвогрунта в сравнении с оценкой этого сопротивления в произвольно сложных состояниях напряжений. Это может приводить к более быстрому износу или превышению устойчивости режущих почву орудий.