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THE HISTORY OF CREATION AND THE ESSENCE OF THE COMBINED SOILS TESTING OF PENETRATION AND ROTATIONAL CUT METHOD

In the early 1960s, the USSR geotechnicians were given the assignment to develop the non-rock soils strength characteristics determining method in order to enable the operative tracked and wheeled vehicles passage estimation through the cross country. As a result of theoretical justification alongside the approbation in lab and field conditions by the group of professionals, there was developed a new method of soils strength investigation by the way of joint penetration and rotational cut testing. A new method of estimating soils strength undergone the overall investigation in different soils environments of the European part of USSR, particularly in Karelia – on stripped clays, center and the south of Ukraine – on sands and loess loams, Moscow region – on heavy clay soils. The prototype equipment allowed conducting the research in the cross country, shallow water areas, on the river beds and bottoms of the lakes. In 1970 the equipment and methodology of joint penetration and rotational cut testing were used during the Moon surface investigation by Lunokhod-16 apparatus.

Keywords: *soils strength investigation method by the way of joint penetration and rotational cut testing, soils strength, rutting.*

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ІСТОРІЯ СТВОРЕННЯ ТА СУТЬ МЕТОДУ СУМІСНИХ ВИПРОБУВАНЬ ҐРУНТІВ НА ПЕНЕТРАЦІЮ Й ОБЕРТАЛЬНИЙ ЗРІЗ

Розкрито історію створення методу визначення характеристик міцності нескельних ґрунтів на початку 60-х років минулого століття геотехніками СРСР. Унаслідок теоретичного обґрунтування з апробацією в лабораторних та польових умовах групою фахівців було розроблено новий метод дослідження міцності ґрунтів шляхом сумісних випробовувань на пенетрацію й обертальний зріз. Описано процес усебічного дослідження методу оцінювання міцності ґрунтів у різних ґрунтових умовах Європейської частини СРСР, а саме в Карелії – на стрічкових глинах, у центрі та на півдні України – на пісках і лесованих ґрунтах, у Московській області – на важких глинистих ґрунтах тощо. Розглянуто дослідні зразки відповідної техніки, що дозволяли проводити дослідження в умовах бездоріжжя, мілководних акваторій, на дні річок та озер. Доведено, що у 1970 році обладнання і методика сумісних випробовувань на пенетрацію та обертальний зріз були використані при дослідженні поверхні Місяця апаратом Луноход-16.

Ключові слова: *сумісні випробовування, ґрунт, пенетрація, обертальний зріз, міцність, колієутворення.*

Introduction. In the 1960s there was a necessity of developing the express method of determining soils strength characteristics in order to estimate the passage possibility of tracked and wheeled vehicles through the cross country. A contractor was the Ministry of Defense of USSR, the task was entrusted by the All-Union Scientific and Research Institute of Hydrogeology and Engineering Geology (AHEG) in Moscow. A Senior Scientific Associate of the AHEG Vadym Fedorovych Razorenov was appointed as a division head for the task.

In 1962 at Poltava engineering construction institute (PECI) there was a post-graduate school opened for the 05.23.02 «Bases and Foundations» specialty. Professor Evgenii Volodymyrovych Platonov was appointed as its supervisor. Platonov and Razorenov once worked together on the ferry crossing construction of Crimea-Caucasia and shared the same scientific interests ever since. According to Razorenov's suggestion, the post-graduates of Poltava ECI were envolved into the development of the problem as crewmen of a geological expedition of AHEG. A fieldwork on the subject started in 1963. The crew consisted of V.F. Razorenov, V.D. Shytov and the chief of geological expedition – T.A. Demcnuk from the AHEG, from Poltava ECI the crew was joined by the post-graduates: V.H. Khilobol, H.V. Zhornik, V.H. Zabara, M.L. Zotsenko, I.N. Skryl. Structural works performed by Alexander Mozhaysky Military Space Academy employees under command of colonel P.I. Eizler [3, 4].

Analysis of recent sources of research and publications. It is known that the passage possibility of tracked and wheeled vehicles through the cross country estimated by the depth of the rut left by vehicles moving along the same route. When the rut depth reaches the vehicle clearance, its movement is terminated due to friction of the vehicle bottom against the soil. Tracks and wheels keep rotating which just deepens the rut [11, 12]. A process of rutting is caused by soils destruction, which is estimated in soil mechanics by the loose of soil strength. According to the Coulomb law, the characteristics of soil strength are internal friction angle φ and specific cohesion c. Thus, for rutting prediction, it is necessary to determine these characteristics for soils on the traffic intervals to the depth of about 1 m [5, 7].

Identification of general problem parts unsolved before. According to state standards of that time, strength characteristics of soils estimated in laboratories after planar shear tests of soil samples. For military purposes, it was necessary to develop a new, field method that would allow prompt soil testing during the scout vehicle motion. That would allow prediction of the rutting process for estimation of passage possibility of tracked and wheeled vehicles through the cross country. In the early 1960s in the USSR and abroad the field methods of soils characteristics investigation via penetration, dynamic and static probing, rotational cut, were actively developing [13, 14, 19, 20]. Using penetration or probing there was determined the average characteristic of soil – penetration resistance (probing resistance) which was a function of internal friction angle and cohesion [15, 16].

The **goal** was, using the rotational cut for clay soils, to determine a specific cohesion only [8, 9].

Basic material and results. Basic material and results. In 1962 V.F. Razorenov [5] suggested the idea of combining the static penetration (probing) and rotational cut in a single device. Using the data obtained from it, it would be possible to determine separately the characteristics of soils strength for conducting the geotechnical calculation including the rutting.

Penetration is a method of soils characteristics investigation by the way of estimating the soil resistance to submerging the bits of different shapes and sizes. There are distinguished the penetration such as when bit penetration depth does not exceed its height and probing – when the depth is greater than a size of a bit. Penetration is used in lab and field environment for shallow soils testing. Probing is used in a process of field soils testing along the depth of its occurrence [17 – 19].

The rotational cut is a method of soil properties investigation by the determination of soil resistance to rotation of winged bit with the four orthodox paddles (Fig. 1, a). It is considered that when the winged paddle submerges on its own height only, the shear surface of soil consists of cylindrical and bottom circular, created by wing rotation.
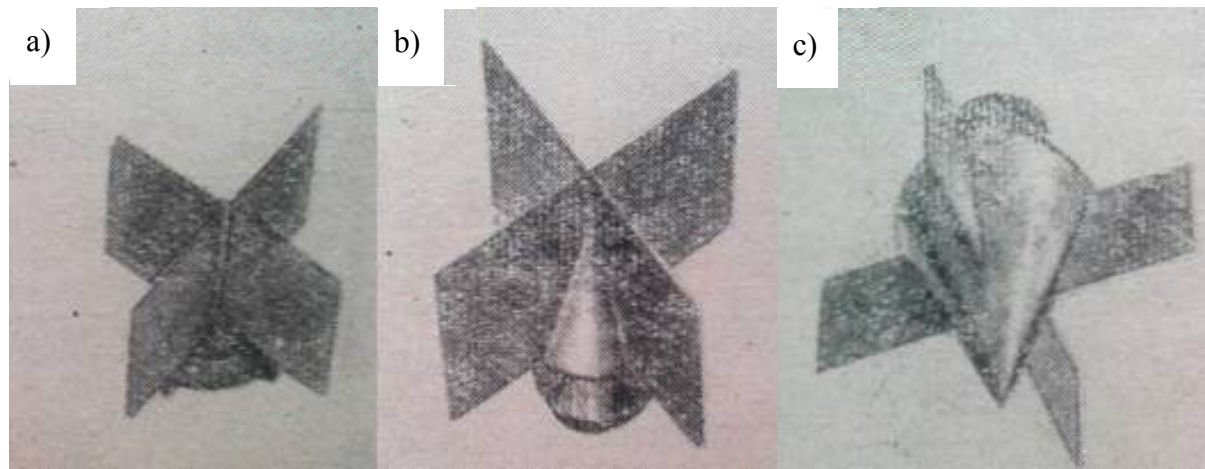

Figure 1 – Combined bits for conducting the joint penetration and rotational cut testing:
a – winged bit; b – bit with the wing along the whole its height;
c – bit with awing in the top part of the cone

If the winged bit is submerged in soil to the depth greater than its height, the top circular surface will contribute to the total shear surface. The limit resistance to rotational cut τ is estimated by the formula:

$$\tau = \frac{M_{max}}{k_\tau}, \text{ kPa,} \tag{1}$$

where M_{max} – maximal external moment, applied to a winged bit; it is determined by the correlation diagram of winged bit rotation angle β and rotational cut resistance τ;

k_τ – static moment of rotational cut surface resistance with a single circular surface is determined by:

$$k_\tau = \frac{\pi D^2}{2}(\frac{D}{6} + h), \text{ cm}^3, \tag{2}$$

– with two circular surfaces, is determined by the formula

$$k_\tau = \frac{\pi D^2}{2}(\frac{D}{3} + h), \text{ cm}^3, \tag{3}$$

As a result of numerous experimental studies for combined penetration tests and rotational cut, combined bit of P.I. Eizler design was adopted. It had cone shape with an opening angle of 30^0 with a wing at the top part of it (fig. 1, c) [9 – 10]. The lower part of the conical tip is used for penetration. Then the tip plunged into the ground at full height and a rotational cut was performed. It was this version of combined tests for penetration and rotational cut that was adopted to solve the problems of rutting and later, for lunar soil studies.

For a combined tip with blades in the upper part, the following formula is used

$$k_\tau = \frac{\pi D^2}{2}\left[\frac{1}{6}(D - \frac{d_{con}^2}{D^2}d_{con}) + h_w\right], \text{ cm}^3, \tag{4}$$

where d_{con} – diameter of cone base, cm;
D, h_w – diameter and height of wing, cm.

When testing clay soils by a rotational cut from the surface, the soils own weight can be neglected, in this case, a specific cohesion c equals to limit rotational cut resistance τ [5]. Then, according to the results of the rotational cut, the specific cohesion of soil c is directly determined. Professor V.G. Berezantsev, based on the theory of limit equilibrium of cohesive soils, [1] established functional dependence of the type

$$c = k_\varphi R \, , \qquad\qquad (5)$$

where k_φ – coefficient of proportionality, depending only on the angle of internal friction of the soil φ. V.G. Berezantsev represented this dependence by the graph in Fig. 2.

Thus, determination of the specific adhesion c and the angle of internal friction φ of clay soils in the range of their natural strength is carried out using a combined tip with blades at the base of the cone of the P.I. Eizler's design. in the following order:

– initially, the conical part of the tip is immersed in the ground, while penetration is performed with the determination of penetration specific resistance R;

– then the upper part of the combined tip with the wing is pressed into the ground and a rotational cut is made to determine the specific cohesion c of the soil;

– according to the received data, the coefficient k_φ is established, according to which using the graph in Fig. 2, the value of the internal friction angle φ is determined

$$k_\varphi = \frac{c}{R} \, , \qquad\qquad (6)$$

In laboratory conditions, the combined tests of clay soils on penetration and rotational cut method has been introduced into the educational process as a lab practical in studying the course of Soil Mechanics. The device for carrying out this lab practically is shown in Fig. 3.
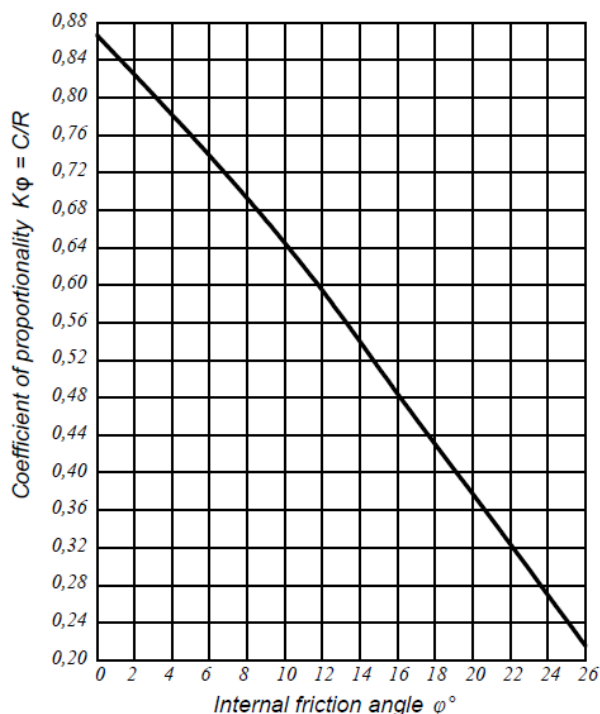

Figure 2 – Graph of the dependence of the coefficient k_φ on the angle of internal friction of the soil φ

Figure 3 – «Camomile» device

It is a standard laboratory consistometer equipped with rotary section «Chamomile» attachment of P.I. Eisler's design. A sample of soil is taken into a metal ring with a diameter and height of 70 cm. On one side of the sample, a penetration test is performed with a conical tip with an opening angle $\alpha = 30^0$ to determine the specific resistance of penetration R. After that, the rod with the cone is removed, the ring with the ground is rotated on the reverse side to perform a rotational cut with a wing-shaped tip (Fig. 1, a).

For this purpose, the ground ring is rigidly attached to the attachment disc. The bar with the wing is rigidly fixed to the bracket to prevent it from turning. The rotational moment on the wing is transmitted through the ground by rotating the disc under the weight of a stepped application of the weights onto the suspension. Experience is considered to be completed when wing makes a turn in the ground. The result wing rotation angle dependence in the ground on the magnitude of the rotational cut torque. The limit resistance to the rotational cut τ is determined by the formula (1).

With soils studied surface, the ultimate resistance of the rotational cut is equal to the specific cohesion. The angle of soil internal friction is determined from the graph in Fig. 2. It should be noted that the combined test method for penetration and a rotational cut is not used for engineering and geological surveys, it is not available in state regulatory documents. Experimental studies of Zhornik G.V. [10]. convincingly proved that with an equal degree of objectivity in establishing the characteristics of soils strength, conducting costs are much lower than for planar shear.

To test the technique of combined tests for penetration and rotational cuts in various soil conditions, mechanical penetrometers were installed on high-throughput machines, three of which are shown in Fig. 4.

a)   b)   c)
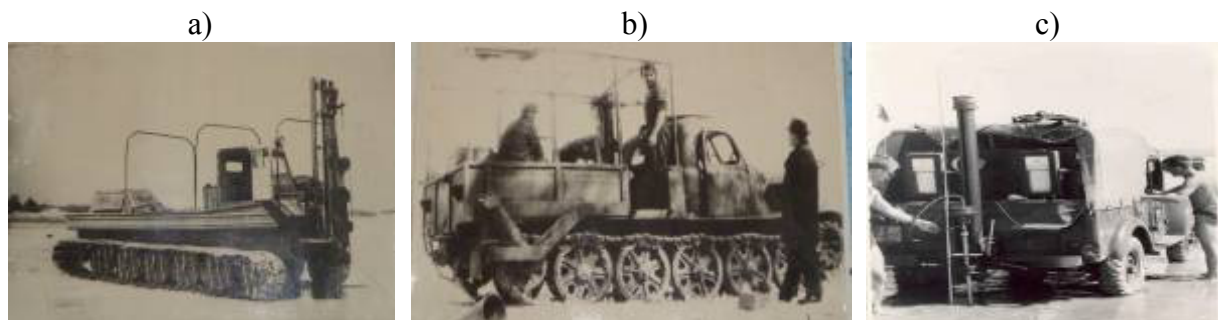
**Figure 4 – Machines of various patency
with mechanical penetrometer designed by P.I. Eizler:**
a) floating swamp-boat for work in the water area; b) light artillery tractor; c) car GAZ-69

With the help of these machines in the period from 1963 till 1966, the technique of penetration and rotational cut was worked out in various soil conditions of the USSR European part from Karelia to the southern Ukraine. Experimental samples of the appropriate technology allowed to conduct research in the conditions of impassability, shallow water areas, at the bottom of rivers and lakes. Based on the results of these studies, the report was compiled, which was accepted by the customer with a high rating [11, 12].

In 1970, Lunokhod-1 was sent to the moon, a mechanized penetrometer was installed on board, it was equipped with a combined tip with blades at the base of the cone of Eizler P.I. design. To assess the characteristics of lunar soil strength, the technique of combined penetration and rotational shear tests was used. In Fig. 5 Lunokhod-1 scheme with the equipment specified is shown. According to our data, the described method of soil investigation, in the modern modification, is now used on space vehicles of different countries that visit the nearest planets.
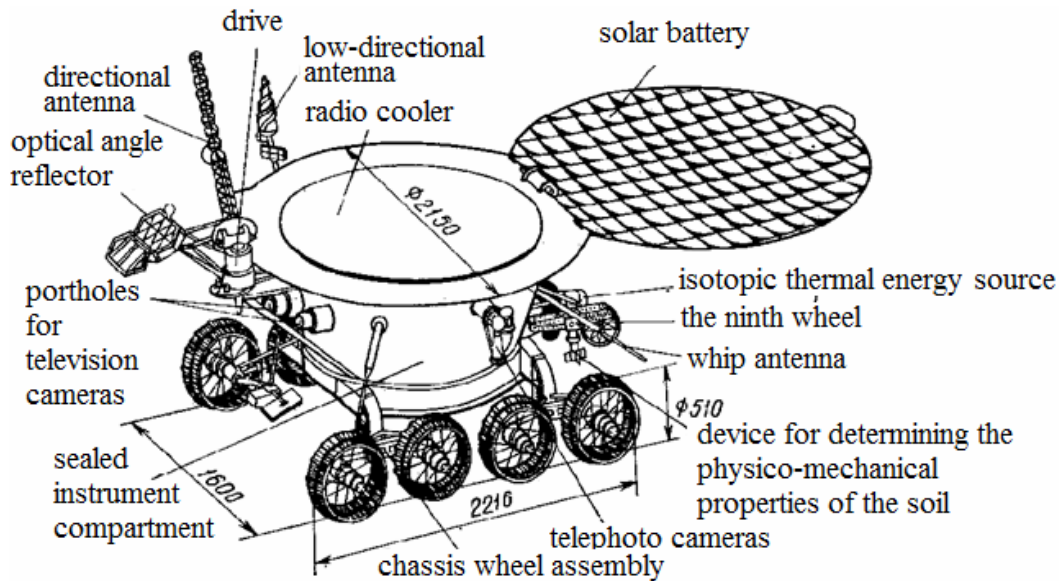
Figure 5 – Operational scheme of Lunokhod 1

Conclusions. The existing experience of using the combined test method for penetration and rotational cut in the process of engineering and geological survey shows its efficiency, economy and sufficient accuracy in determining soils strength characteristics. For obvious reasons, it has not been standardized for a long time and therefore has not received wide circulation.

Today, when reviewing the State Building Standards of Ukraine, namely DSTU B.V.2.1-3-96 (GOST 30416-96) «Soils. Laboratory tests. Terms» it is considered the soils combined tests method should be included in the regulatory framework of the state as an alternative to the planar shear method.

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