Determination of mechanical properties of soil under laboratory conditions

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Abstract

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This paper presents the mechanical properties of soil. In order to determine the properties of soil under laboratory conditions, a special measuring device was constructed, viz. a bevameter. Two types of soil with different levels of moisture were examined and their mechanical properties were determined. Measurements were taken of non-compressed soil. A measuring network was set up, consisting of measuring and recording devices. In the course of measuring, the force and penetration depth of the pressing plate were recorded simultaneously. Three different diameters of pressing plate were used, namely 38, 50 and 70 mm. The pressure on the contact area was calculated after completion of the measurements, and the relationships between pressure and penetration depth were presented graphically.

Keywords: pressure; penetration depth; bevameter; soil moisture

The use of mobile machines in agriculture causes undesirable soil compaction, resulting in changes in soil properties. The degree of soil compaction can be determined by measuring the physico-mechanical properties of the soil. Once this has been achieved, adequate steps may be implemented to improve soil conditions, e.g. by applying protective technologies of soil cultivation. There is a real need for the determination of soil properties, under laboratory conditions as well as under real-life operating conditions.

Under laboratory conditions more exact and objectively comparable results can be obtained. The scientific importance of the study of these results lies in the field of terramechanics. At present, several methods are known for determining the physico-mechanical properties of soil, and a number of appropriate measuring devices and measuring tools is used. From a historical and factual point of view, the valuable theoretical and practical work carried out by Bekker (1961, 1969) and his disciple Wong (1980, 1989) should be noted. Based on extensive experiments and theoretical analyses, Bekker (1961) described in mathematical terms the physical reactions taking place in the contact zone between wheel and soil. From this he derived the basic relationships for vertical and horizontal force effects (penetration and rolling-resistance) resulting from the movement of the wheel over the soil. All his mathematical derivations are based on the experimental data obtained through the use of measuring devices and measuring equipment. The measurements were carried out in laboratory conditions, each penetration test being performed at least twice. Round plates of various diameters were used, whereby the penetration depth of the plates was recorded together with the pressure exerted. Bekker (1961) made use of a measuring device called a "bevameter", which serves experimentally to determine:

– penetration depth in relation to pressure exerted,
– shear stress related to soil movement.

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Table 1. Granularity of soil samples

Soil sample	Soil particles according to size (%)				
	> 0.25 mm	0.25–0.05 mm	0.05–0.01 mm	0.01–0.001 mm	< 0.001 mm
Z1	6.16	5.57	53.8	17.92	16.55
Z2	40.49	13.52	25.67	10.61	9.71

In Slovakia, Bajla (1998) has spent considerable time studying the mechanical properties of soil. He performed extensive experimental measurements using a vertical and horizontal penetrometer of his own construction. Also, Varga (2010) has performed extensive measurements of the mechanical properties of soil, with a view to determining the effect of soil resistance in the case of a uniform plowing depth through the use of a three-point hitch tool pulled by a tractor. The deformation characteristics of soil at compressive load under laboratory conditions were reported by Abrahám (2005).

MATERIAL AND METHODS

For determination of mechanical properties of soil at simple load by pressure under laboratory conditions a measuring device specially designed at the Department of Machine Design, Faculty of Engineering, Slovak University of Agriculture in Nitra, Slovakia was used. This measurement device with accessories (Fig. 1) consists of a single-phase asynchronous motor Klimac KT1 type (ZPA, Prešov, Slovak Republic). The motor is equipped with limit switches and an overload protection (OP KT1; ZPA, Prešov, Slovak Republic), which is adjustable with a spring preload of the torque clutch. The shaft of the motor is connected to the gear box (Klimac KT 1; ZPA, Prešov, Slovak Republic) by input-shaft. This gear box drives the spindle nut, which is attached to the double-wing propeller of the optoelectronic revolution sensor (RS; DMD SUA, Nitra, Slovak Republic). The optoelectronic force sensor (SS 1000N; DMD SUA, Nitra, Slovak Republic) is mounted between the sliding bar of the spindle and the pressing plate. A soil sample is placed in a metal container. Based on the number of spindle nut revolutions and the thread pitch s = 6 mm, the penetration depth of the pressing plate can be set. The pressure value depends on the force and surface area of the pressing plate. The data measured are continuously processed by computer, displayed on a monitor and recorded on a recording device (PC-IBM; IBM, New York, USA).

The laboratory measurements of the mechanical soil properties at simple pressure load were performed under following conditions. The soil was moistened to the desired moisture before the experiment and then placed in a container with dimensions 640 × 440 × 400 mm up to a height of 370 mm.

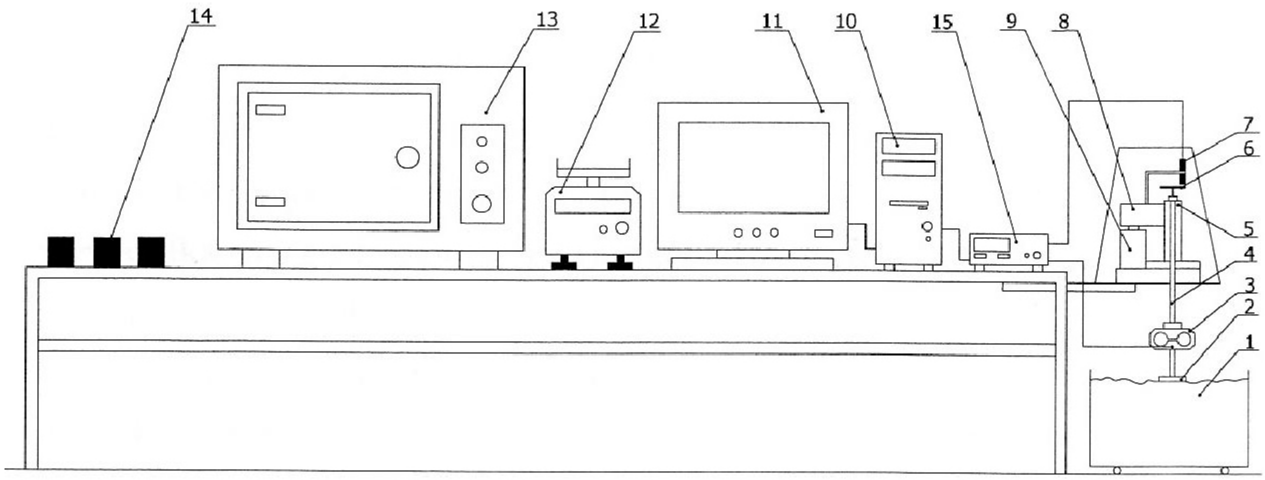

Fig. 1. Measuring network for measurement and evaluation of the bevametric test

1 – metal bin with soil; 2 – pressure plate; 3 – force sensor; 4 – displacement rod of servomotor; 5 – arbor nut; 6 – two wing propeller; 7 – rpm sensor; 8 – gearbox; 9 – single phase asynchronous electric motor; 10 – computer; 11 – monitor, 12 – weight; 13 – drier; 14 – sample; 15 – recorder

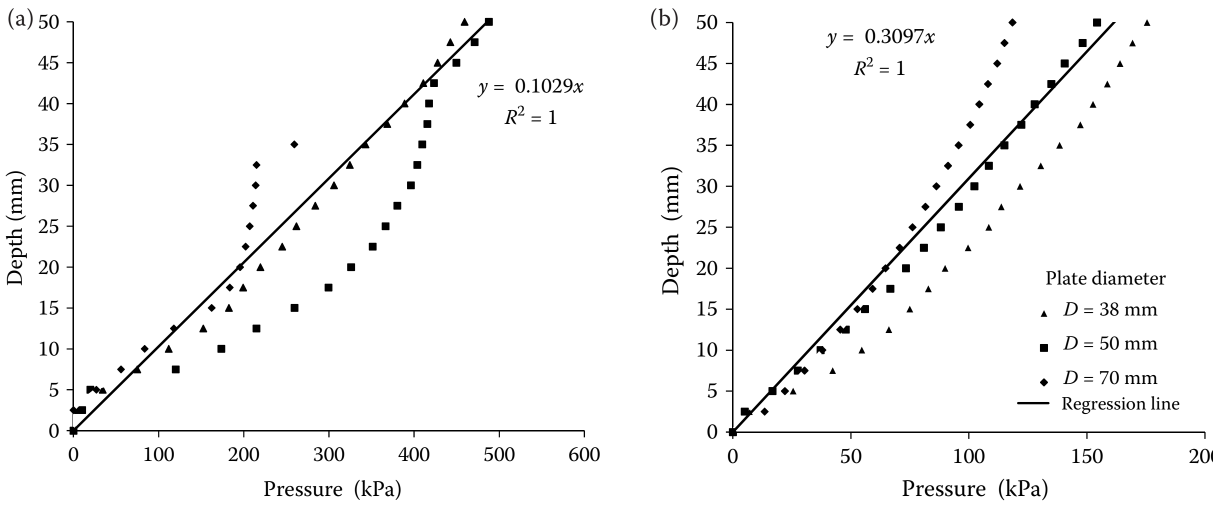

Fig. 2. Relationship between pressure and depth for soil moisture (a) 4.8%, (b) 16.03% and granularity Z1

For the laboratory measurements, following soil samples were used:

– soil moisture 4.81% and 16.03%, granularity Z1,
– soil moisture 5.7% and 17.03%, granularity Z2.

The soil moisture mentioned above is expressed in weight percentage. The granularity of soil samples is presented in Table 1.

RESULTS AND DISCUSSION

The results obtained from the experimental measurements of soil compaction using a bevameter, with soil moisture w = 4.81% and granularity Z1 confirm that penetration depth h increases linearly in relation to pressure p (Fig. 2a). It can be further observed that plate diameter has an effect on the penetration depth for the same value of pressure. In this case the relationship between pressure and penetration depth may be expressed by regression line $y = 0.1029x$ with correlation coefficient $R^2 = 1$, as shown Fig. 2. For example for a pressure p = 400 kPa and plate diameter D = 50 mm the penetration depth is 40 mm.

Different results were obtained for soil moisture w = 16.03% and the same granularity Z1 (Fig. 2b). Fig. 2b shows that for pressure p = 100 kPa the penetration depth is approximately 30 mm. Similar results were obtained for granularity Z2 and analogous values of soil moisture, as compared in Fig. 3. Ultimately, the summary diagram shown in Fig. 4 graphically illustrates the results obtained from the experimental measurements of soil compaction for various soil moisture and granularity levels.

Based on the obtained results mentioned above it can be concluded that dry soil with a moisture level about 5% does not change expressively its mechanical properties, not even after compression and regardless of granularity. However, at a level of soil

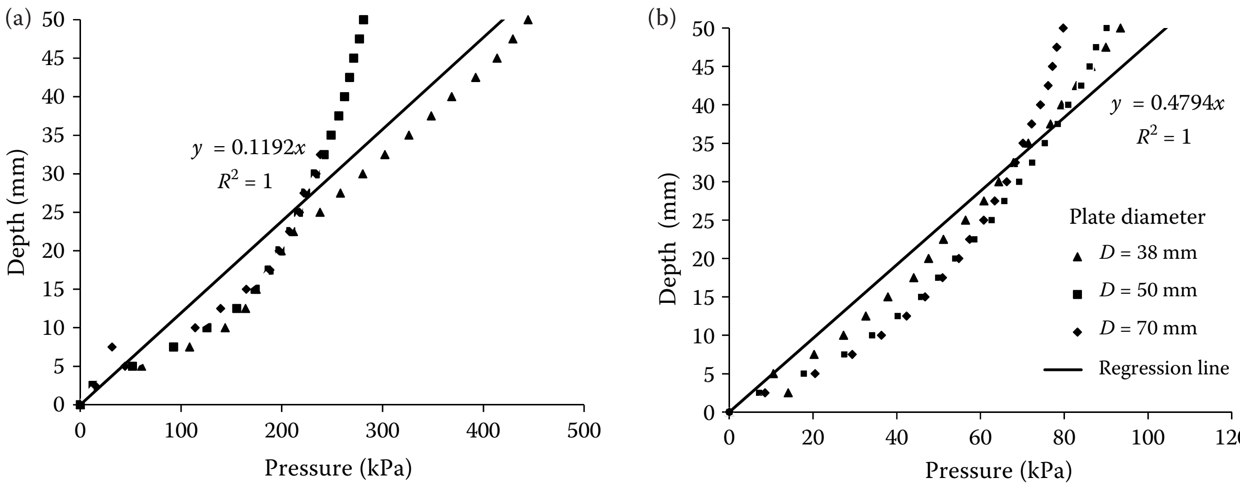

Fig. 3. Relationship between pressure and depth for soil moisture (a) 5.7%, (b) 17.03% and granularity Z2

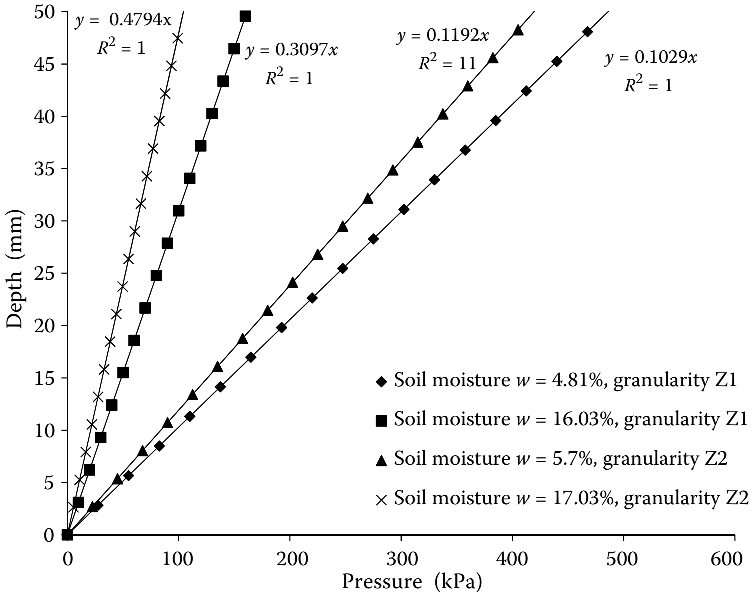

Fig. 4. Relationship between pressure and depth after regression analysis for various soil moisture and granularity levels

moisture of 16–17% the change in mechanical soil properties after compression is the highest of all, up to 4-fold.

So, in view of the fact that the most favourable moisture level for standard types of soil for cultivation is within 15–17% range, it is recommended to use all available means (dual tyres, caterpillar tractors, soil protection technologies) to reduce soil compaction caused by mobile agricultural machines.

CONCLUSION

The laboratory experiments and measurements identified a number of new relationships which have, up to now, never been presented in this way, and which need to be further theoretically analysed. In the first place, there is an interesting fact that reduction in plate diameter, and thus in the surface area of the pressing plate, will generally little decrease the pressure for the same value of penetration depth; it may be considered as anomaly or paradox. This paradox may be explained by the fact that by pressing the plate into the soil, the soil is compressed on area equal to the surface area of the plate, while at the same time soil is cut and pushed away at the circumference of the plate. However, in calculating the pressure values, the shear stress at the circumference of the plate is not taken into consideration. As a result, the pressure values are to some extent distorted.

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