

## Effects of tillage operation on soil properties from Pakdasht, Iran

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**A b s t r a c t.** Soil mechanics has of late, taken on a new significance as a field worthy of expended research and application. The basic problem encountered in this field is the determination of certain basic parameters and fundamental principles involved which facilitate a logical evaluation of the system. The characterization soil parameters are of great importance for determining the off-road vehicle performance and the rolling resistance of agricultural soils. One of the well-known methods for measuring the vehicle performance and mobility is that proposed by Bekker. In Bekker's equation  $k_c$ ,  $k_p$  and  $n$  are pressure-sinkage parameters. Based on Bekker's model three types of terrains (plowed soil, disked soil and dirt road) were considered for determine the pressure-sinkage parameters. Hence a bevameter was developed that consisted of movable chassis, three rectangular plates and a slide gauge. Sigmaplot software was applied for plotting and graphical solution the Bekker's equation. Tests were replicated three times for each of the rectangular plates in each of the three types of terrains. Results identified that the type of tillage operation and soil bulk density affect the values of  $k_c$  and  $k_p$  parameters. However, the effect of soil bulk density on the value of  $n$  was not significant.

**K e y w o r d s:** bevameter, pressure-sinkage relationship, sinkage plates, soil properties

### INTRODUCTION

The interactions between the surface soil and the running gear of a vehicle have two effects namely the tractive effort and the motion resistance which allow and limit the movement of the vehicle, respectively. The sinkage of the running gear causes a motion resistance which is opposed to the tractive capacity of the vehicle which is variable according to the soil type. In a homogeneous soil, the sinkage is predicted by the interpretation of plate sinkage tests (Benoit and Gotteland, 2005). The plate sinkage test has been used widely in terrain-vehicle engineering (Earl and Alexandrou, 2001).

Soil information is required in precision agriculture for terrain trafficability. The terrain characterization has been the subject of several studies. Perhaps the best known and widely cited work is that of Bekker and Wong (1978). From the point of view of terramechanics, soil can be characterized by determining the terrain parameters (Ojeda *et al.*, 2005). The traditional models started with Bernstein and Lestoshnev in 1913, which Bekker and Reece modified to be more suitable for applications to agricultural soils. Bekker's model and sinkage plates were applied to determine the physical mechanics of soil sinkage (Leis, 1961). Base on this model the value of the rolling resistance due to soil compaction, can be approximated by assuming that the energy required to overcome the rolling resistance is equal to the work done in deformation the soil. The other models considered the acceleration, shape of the loading surface and velocity on the values of the pressure-sinkage parameters (Abou-Zeid, 2004). Pressure-sinkage tests are also conducted with the device to yield a pressure-sinkage relationship for the soil near the surface for trafficability considerations (Okello, 1991). Earl and Alexandrou (2001) considered deformation processes below a plate sinkage test on sandy loam soil. Gotteland and Benoit (2006) applied the sinkage plate tests for mobility study, modeling and experimental validation. Rashidi *et al.* (2006) used rectangular plate to predict soil pressure-sinkage behaviour under rectangular region.

In this research with application a bevameter the pressure-sinkage parameters of three types of terrains (plowed soil, disked soil and dirt road) were determined and considered based on Bekker's model.

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MATERIALS AND METHODS

Theory

When a load is applied to the surface of a soil a reduction of soil pore volume occurs. Also soil shear at edges of the loading plate takes place. The loaded area sinks into the soil to a certain depth until the soil's resistive force is in equilibrium with the applied force; therefore, sinkage of soil occurs. Resistance of soil to applied pressure can be characterized in terms of two parameters: cohesiveness, the bonding of the soil particles, and the angle of internal friction which is the resistance of movement between soil particles (Abou-Zeid, 2004). Many different methods and devices have been used for quantifying soil reactions to applied forces, but, penetration resistance and soil density measurement are the most used techniques (Ronai and Shmulevich, 1995).

If the track is pulled a distance  $L$  in the horizontal direction, the work done by the towing force, which is equal to the magnitude of the motion resistance due to terrain compaction, can be equated to the vertical work done in making a rut of length  $L$ . For the measurement of the vertical soil strength the plate-sinkage test has become widely accepted. The principle is depicted in Fig. 1 to regard the influence of the plates of different sizes are used for testing. The result of the measurement is the pressure versus the sinkage (AESCO, 2005). These measured curves can be approximated by a simple exponential equation for homogeneous terrain, which was proposed by Bekker (1956):

$$p = \left( \frac{k_c}{b} + k_\varphi \right) z^n, \quad (1)$$

where:  $p$  is the contact pressure ( $\text{kg cm}^{-2}$ ),  $b$  is the width of a rectangular sinkage plate (cm),  $z$  is the sinkage (cm),  $n$  is the exponent of deformation,  $k_c$  is cohesive modulus of deformation ( $\text{kg cm}^{-(n+1)}$ ) and  $k_\varphi$  is frictional modulus of deformation ( $\text{kg cm}^{-(n+2)}$ ). The values of  $p$  and  $z$  are measured while the parameters  $k_c$ ,  $k_\varphi$  and  $n$  are derived by fitting experimental data to the Eq. (1).

The values of  $k_c$ ,  $k_\varphi$  and  $n$  can be derived from the results of the test with two sizes of plates having different widths:

$$\begin{aligned} p_1 &= \left( \frac{k_c}{b_1} + k_\varphi \right) z^n, \\ p_2 &= \left( \frac{k_c}{b_2} + k_\varphi \right) z^n, \end{aligned} \quad (2)$$

On the logarithmic scale, the Eq. (2) can be rewritten as follows:

$$\begin{aligned} \log p_1 &= \log \left( \frac{k_c}{b_1} + k_\varphi \right) + n \log z, \\ \log p_2 &= \log \left( \frac{k_c}{b_2} + k_\varphi \right) + n \log z. \end{aligned} \quad (3)$$

They represent two parallel straight lines of the same slope on the log-log scale as shown in Fig. 2. It is evident that  $\tan \alpha_s = n$ . Thus, the exponent of deformation  $n$  can be determined from the slope of the straight lines (Wong, 1978). Owing to the nonhomogeneity of the terrain in the field and possible experimental errors, the pressure-sinkage lines may not be quite parallel on the log-log scale in some cases. Therefore, two values of  $n$  are usually taken as the mean of the two values obtained. Thus in the Eq. (3)  $p$  and  $z$  are measured values with the bevameter, and the only unknowns are  $k_c$  and  $k_\varphi$ .

Experimental procedure

In this research a bevameter was developed to determine pressure-sinkage parameter in three types of terrains. As illustrated in Fig. 3 this bevameter consisted of movable

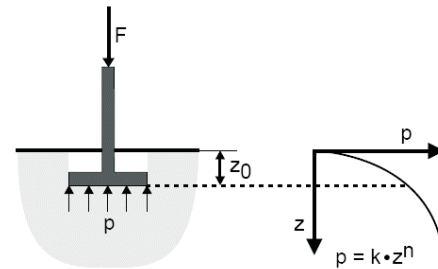


Fig. 1. Principle of the measurement of the vertical soil strength (pressure-sinkage relationship).

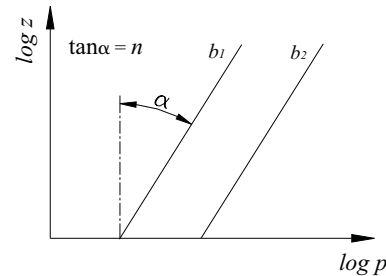


Fig. 2. Method for determining sinkage moduli and exponent.

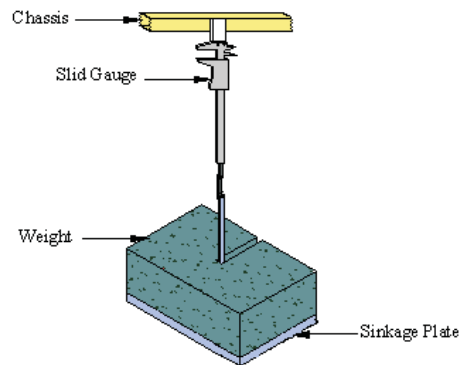
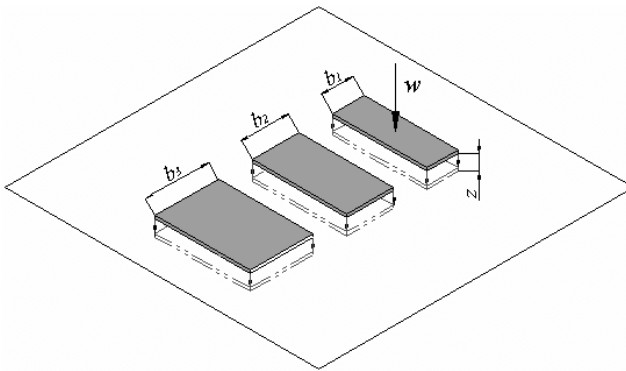


Fig. 3. Schematic view of the bevameter.

chassis, three rectangular plates and a slide gauge. Three rectangular plates with different aspect ratio (length/width) were applied for carry out the experiments. In view of the possible localized nonhomogeneity in the field, however, the width of the plate designed for field use should not be less than 5 cm, and preferably not less than 10 cm (Wong, 1978). Thus, the least width of plates was selected 10 cm and the aspect ratio of these plates varied from 1.75 to 3.5. The three plates had the same length. The dimensions of plates are given in Table 1. Schematic view of the sinkage plates is shown in Fig. 4. Three types of terrains have been considered in this research.

**Table 1.** Sizes of sinkage plates

Sinkage plate	Width (cm)	Length (cm)	Aspect ratio
1	10	35	3.50
2	15	35	2.34
3	20	35	1.75



**Fig. 4.** A schematic picture of the sinkage plates.

Plowed soil with depth 18 cm: This type of soil was sandy-loam which consisted of 48.00 silt, 46.16 sand and 5.84% clay. The measured soil moisture content and apparent bulk densities were 1% d.b. and  $1.14 \text{ g cm}^{-3}$ , respectively. Applied plow was integral with three general purpose bottoms.

Disked soil (with disk harrow): This type of soil was silt-loam one which consisted of 60.00 silt, 32.16% sand and 7.84% clay. The measured soil moisture content and apparent bulk densities were 3.3% d.b. and  $1.04 \text{ g cm}^{-3}$ , respectively. Applied disk was tandem integral and had six disks on each gang with 165 mm blade spacing and 448 mm blade diameter.

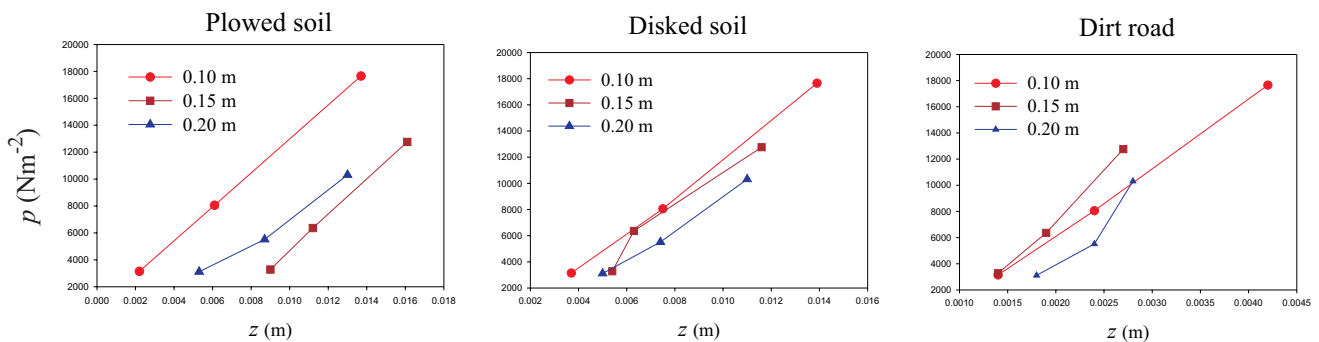
Dirt road soil: This type of soil was silt-loam which consisted of 68.00 silt, 22.16 sand, and 9.84% clay. The measured soil moisture content and apparent bulk densities were 3.5% d.b. and  $1.33 \text{ g cm}^{-3}$ , respectively.

The loading sinkage plates were repeated three times in each of the three types of terrain. Experimental results for mentioned above soil are shown in Fig. 5.

As shown in Fig.5 the pressure-sinkage curves in disked soil and dirt road were not linear for plates with the width 15 and 20 cm, respectively. Thus, soil parameters obtained for these plates didn't be enough accuracy. It should be noted that can be derived the results of the test with two sizes of plates. Hence, by using graphical method and Eqs (2) and (3) can be incard the non-linear graph of plates.

## RESULTS AND DISCUSSION

The  $k_c$ ,  $k_\phi$  and  $n$  constants were calculated using two rectangular plates with different aspect ratios for three types of terrains. Based on the obtained results type of the tillage operations has effect on the value of soil parameters. The results of the pressure-sinkage tests for three types of terrains were plotted in logarithm scale based on Eq. (3). As shown in Fig. 6 the values of the  $\log z$  versus  $\log p$  were plotted for two selected plates. The values of the  $n$  were determined from the mean of the slope of the straight lines with Sigmaplot software. Then the values of  $k_c$  and  $k_\phi$  were determined from Eq. (2).



**Fig. 5.** Pressure-sinkage relationship for each of the three types of terrain.

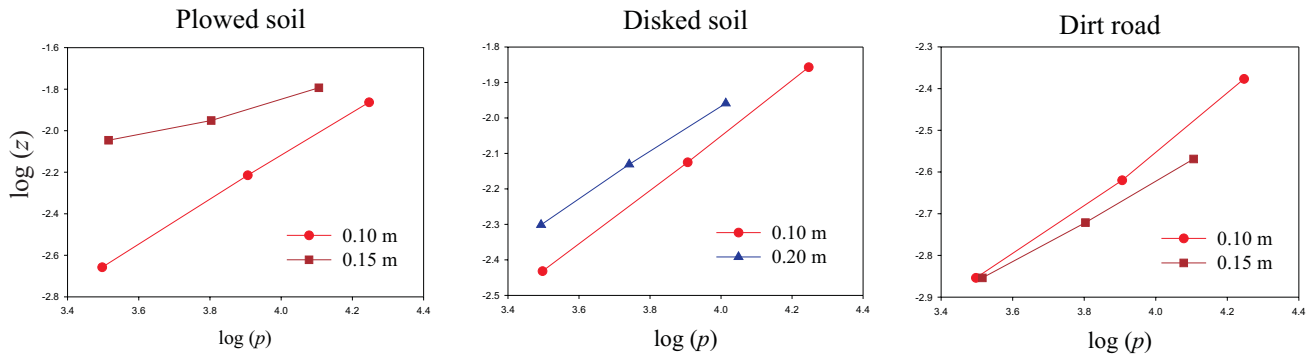


Fig. 6. Pressure-sinkage lines selected on the log-log scale.

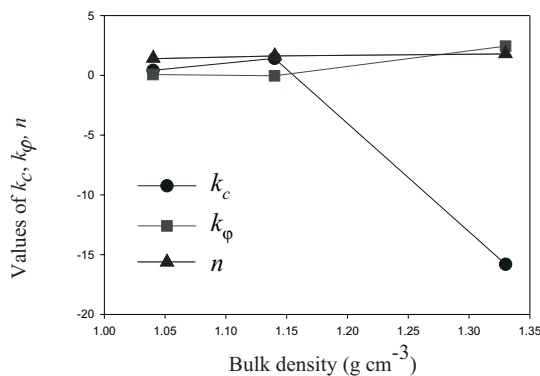


Fig. 7. Diagram of the values of soil parameters against the soil bulk density.

Table 2. Values of k<sub>c</sub>, k<sub>φ</sub> and n for three types of terrain

Soil	k <sub>c</sub> (kg cm <sup>-(n+1)</sup> )	k <sub>φ</sub> (kg cm <sup>-(n+2)</sup> )	n	Bulk density (g cm <sup>-3</sup> )
Dirt road	-15.8	2.44	1.82	1.33
Plowed soil	1.42	-0.036	1.62	1.14
Disked soil	0.42	0.069	1.41	1.04

In Fig. 7 the soil parameters versus the soil bulk density were plotted. The values of the soil parameters on the three types of terrains (plowed soil, disked soil and dirt road) were given in Table 2. It is evident from this table the values of k<sub>c</sub> and k<sub>φ</sub> were maximized for dirt road. The reason for this is a soil compacted structure. Based on the experimental results, the tillage operations were effective on the values of soil parameters. However, effect of the tillage operation on the value of n was not significant. These results can be very useful to determine the sinkage behaviour of tires and tracks of tractors and agricultural machines in the field.

CONCLUSIONS

1. The tillage operations were effective on the values of soil parameters.
2. k<sub>c</sub> increases with increase soil bulk density.
3. In dirt road the k<sub>φ</sub> was more than plowed and disked soil.

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