Measurements of Soil Parameters Related to Traction

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Abstract It is well known that the soil with different load bearing capacity is exposed to compressive stress of the same magnitude. This results in the formulation of a dense layer within the soil mass, which is poor in hydraulic conductivity and aeration. However a fully instrumented device to measure soil properties relevant to traction has been developed. The device can measure soil sinkage parameters (sinkage constant and exponent) utilizing sinkage plates. Field tests were conducted using four-different circular plates (sinkage tests) in a four different soil type. The results show that the device works well.

INTRODUCTION AND REVIEW OF LITERATURE

The ability of traction device to develop high tractive effort with an optimization of soil compaction depends on traction device characteristics; load applied, and soils type and conditions. Proper evaluation of soil properties will lead to successful prediction of vehicle-terrain performance [1]. The determination of soil strength and other properties can be best performed in the laboratory where tests are conducted under controlled conditions and evaluation procedures are well established. Also, soil properties can be obtained in field (in situ methods). In situ methods of soil strength measurement are to be preferred to laboratory techniques because they have minimum disturbance to the soil and therefore more realistic [2]. Different techniques have been used over the years to measure the mechanical properties of soil and tractive performance of traction device and they have their advantages and disadvantages. Among these techniques was the bevameter, cone penetrometer, shear annulus, van shear test, triaxial shear test, and direct shear test are the techniques most frequently used for evaluating soil mechanical properties. Tire tractive ability depends on tire type (radial, bias), tire geometry (width, overall diameter, section height), lug design, inflation pressure, dynamic load on axle, and soil type and conditions. Soil type and conditions are the most important factors that influence traction [3]. Most empirical traction prediction models use soil cone index to represent soil type and condition. The bevameter technique originally conceived and developed

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by Bekker [4-5], is based on the measurement of vertical and horizontal load-deformation of soil under loading condition similar to those exerted by an off-road vehicle. A penetrometer is a simple device used to characterize the soil in numerical terms. Field measurements of the resistance of soil to static or dynamic penetration of cones of various sizes and shapes are widely employed in a variety of purposes. The cone penetrometer developed by U. S. Army Engineering Waterways Experiment Station (WES) is used for off-road vehicle mobility evaluation [6]. Upadhyaya et al. [7] have presented a review of empirical traction prediction relations which utilize soil cone index to represent soil strength. The soil cone index is a very convenient parameter to use in predicting traction, since it can very easily be obtained in the field. Soil cone index is a composite soil parameter which depends on compressive and shear properties of soil. Since traction is also dependent on compressive and shear characteristics of soil, it is argued that soil cone index can be used to predict traction from a theoretical standpoint. An analogue device such as Bevameter is often used to obtain soil linkage and shear characteristics [1,8]. This device has provision for conducting plate penetration tests and torsional shear tests. Bekker [4-5] has described these types of instruments and their principle of operation in detail.

The objectives of this study are:
(1) To develop a portable instrument to measure soil physical parameters related to traction in situ.
(2) To test the suitability of this device for measuring soil sinkage.

INSTRUMENTED DEVICE

The Single Wheel Tester [8] with its initial design is capable of measuring the tractive performance of off-road traction device. The test rig was modified to measure both plate sinkage and shear stress parameters. The plate sinkage kit has been made to measure force-displacement relation in different soil types. Fig 1 shows the instrumented device developed to measure soil sinkage characteristics. The kit consists of:
1- displacement transducer
2- force transducer
3- adaptore
4- displacement transducer holder
5- penetration plates

The instrument is pressed firmly to the ground during the tests by a hydraulic cylinder attached to the rear of the tractor. The vertical sinkage of the plate is measured by a displacement transducer, while the penetration resistance measured by force transducers. Four different penetration plates (50, 70, 85, and 100 mm diameter) have been made to simulate the effect of tyre width on the tractive performance of the tractor and devices. Different size
plaster can be easily mounted on the
load cell.

**EXPERIMENTAL PROCEDURE**

The mechanical properties of soil are
mainly influenced by its type and
moisture contents. Three different
types of soil have been used in the
analysis and analysed at the soil lab
to identify soil texture and moisture
contents, Table 1 and 2.

![Image](image-url)

Fig (1) Pate-sinkage kit attached to the rear of the tractor

<table>
<thead>
<tr>
<th>Sample No</th>
<th>Equivalent Categories</th>
<th>Mass (gm)</th>
<th>%</th>
<th>Sieve Diameter</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gravel</td>
<td>22</td>
<td>7.3</td>
<td>&gt;2 mm</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td></td>
<td>Coarse sand</td>
<td>25</td>
<td>8.3</td>
<td>2:1.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine sand</td>
<td>193</td>
<td>64.3</td>
<td>1.18:0.075</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Silt</td>
<td>60</td>
<td>20.1</td>
<td>&lt;0.075</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Gravel</td>
<td>12</td>
<td>4</td>
<td>&gt;2 mm</td>
<td>Sand</td>
</tr>
<tr>
<td></td>
<td>Coarse sand</td>
<td>13</td>
<td>4.3</td>
<td>2:1.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine sand</td>
<td>250</td>
<td>83.4</td>
<td>1.18:0.075</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Silt</td>
<td>25</td>
<td>8.3</td>
<td>&lt;0.075</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Gravel</td>
<td>2</td>
<td>0.67</td>
<td>&gt;2 mm</td>
<td>Sand</td>
</tr>
<tr>
<td></td>
<td>Coarse sand</td>
<td>13</td>
<td>4.3</td>
<td>2:1.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine sand</td>
<td>288</td>
<td>95</td>
<td>1.18:0.075</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Silt</td>
<td>-</td>
<td>-</td>
<td>&lt;0.075</td>
<td></td>
</tr>
</tbody>
</table>
The tests were performed by pushing the sinkage plate rame into the soil. The normal load and vertical displacement are automatically recorded by means of data aqesation system connected to the rig. The process is repeated with different plate size in each soil type. FORTRAN programs have been built to do the analysis of the collected data based on the following: The Bekker's pressure-sinkage equation has been used,

\[ p_i = \left( \frac{k_c}{b} + k_\delta \right) z_i^n \]  

(1)

where
- \( p \) is the ground pressure, kN/m²
- \( i \) is the plate number
- \( b \) is the radius of circular plate, m
- \( z \) is the sinkage, m
- \( n \) is the exponent of deformation, non dimensional
- \( k_c \) and \( k_\delta \) are soil parameters.

Taking the logarithm of each side will produce,

\[ \log(p_i) = \log(k_{eq}) + n \log(z_i) \]  

(2)

where:
\[ k_{eq} = (k_c/b) + k_\delta \]

The least square method has been used to fit the relation between \( \log(p) \) and \( \log(z) \). At each site, four different values have been collected and the average of \( n \) for each site was calculated as follows:

\[ n = (n_1 + n_2 + n_3 + n_4) / 4 \]  

(3)

By the same way, the values of \( k_{eq} \) have been used to plot the relationship between \( k_{eq} \) and \( 1/b \), and the least square method has been used to fit a line where the intersection of this line gives \( k_\delta \) and the slope determines \( k_c \).

Typical results of plate-sinkage test are shown in Figs 2 to 7.
Fig 2 Plate sinkage test in Sandy loam soil

Fig 3 keq vs 1/b in Sandy loam soil

Fig 4 Plate sinkage test in Sand I

Fig 5 keq vs 1/b in Sand I

Fig 6 Plate sinkage test in Sand II

Fig 7 keq vs 1/b in Sand II
Table 3 shows the calculated values of plate-sinkage parameters \( k_e \), \( k_\phi \), and \( n \).

Table (2) Plate-sinkage parameters

<table>
<thead>
<tr>
<th>Soil type</th>
<th>( k_e ) (kN/m(^{n+1}))</th>
<th>( k_\phi ) (kN/m(^{n+2}))</th>
<th>( n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td>29.35</td>
<td>2700</td>
<td>1.03</td>
</tr>
<tr>
<td>Sand I</td>
<td>193</td>
<td>1315</td>
<td>1.01</td>
</tr>
<tr>
<td>Sand II</td>
<td>55</td>
<td>1235</td>
<td>0.9</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Based on this study the following conclusions could be reached:

(1) The fully instrumented soil test device has the ability to measure the plate-sinkage parameters with good accuracy.

(2) The device is very simple to use in both laboratory and field.

(3) The device should be completed to measure shear parameters.

REFERENCES