THE IMPACT OF THE PLATE DIAMETER ON THE DETERMINED VALUE OF THE PRE-COMPACTION STRESS OF SAMPLES MADE OF SILT SOIL

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ABSTRACT

The objective of the paper was to investigate the impact of the plate diameter on the value of the measured pre-compaction stress of soil. The investigations were carried out on model samples with 100 mm diameter and 30 mm height made of the silt loam and the percentage moisture content of 13.7 and 21.9%. The following properties of the used material were measured: the granulation group, density of solid particles, humus content, reaction, plastic and liquid limit and the degree of saturation of samples. The samples were loaded with a testing machine using plates with varied diameters: 20, 30, 50, 70, 80, 90, 96, 98 and 99 mm. The pre-compaction stress value was measured with the method of searching for the crossing point of tangents with the secondary stress curve and original stress curve (a classic method). It was found out that for samples with saturation amounting to 13.7% of the moisture content the pre-compaction stress does not significantly depend on the plate diameter. For samples with saturation amounting to 21.9% of the moisture content the pre-compaction stress may significantly depend on the plate diameter. Based on the obtained results a conclusion was made that in the research on the pre-compaction stress with the method of uni-axial deformations, the relation of the plate diameter \((d)\) to the diameter of the cylinder \((D)\) should be within \(0.3 \leq d/D < 0.8\).

Key words: soil, pre-compaction stress, methodology, conditions of deformation

Introduction

Excessive soil compaction by machines and tractors leading to destructive changes in soil properties is one of the most serious problems of the contemporary agriculture (Van den Akker et al., 2003; Błażejczak, 2010). For the quality of soil it is particularly unfavourable to excessively compact the subsoil because the results are long lasting and their removal through deep scarification is energy consuming and sometimes inefficient since in

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some soil and atmospheric conditions may cause greater damages than benefits (Szeptycki, 2003).

Soil compaction increases when its maximum compressive strength is exceeded. The maximum compressive strength value of soil may be characterized with the pre-compaction stress. It is assumed that it is such a value of stress at which elastic deformation of soil changes into plastic deformation (Horn, 1981; Lebert, 1989). It is believed that the knowledge on the pre-compaction stress of soil constitutes important information for the agricultural practice. Since, it allows, together with the knowledge on the distribution of stresses from the pressures on the surface, forecasting the maximum vehicle axle loads the exceeding of which increases the risk of excessive soil compaction (Horn and Fleige 2003).

Utilitarian meaning of the pre-compaction stress causes that this parameter is the object of research in many countries worldwide. However, complexity of the soil environment and constant changes of its properties cause that no standard method of determination of this parameter has not been developed yet (Dias and Pierce, 1995; Błażejczak, 2010). Its value is determined based on the data obtained during soil loading when analysing the course of changes of its deformation as a function of the applied pressure. The experimental curve shape, which is used for determination of the pre-compaction stress of soil is affected considerably by conditions in which tests are carried out, including in particular the soil properties, geometry of the plate and the deformed soil samples as well as the samples’ type (Horn and Lebert, 1994).

The contemporary results of research do not give an explicit answer as to the conditions in which the soil loading should be carried out. Mosaddeghi et al., (2007b) drew the attention to relation between the deformation manner and the course of the experimental curve. They also noticed that soil loading in the unconfined conditions has a higher variability of the gradient of the course of the pressure-deformation curve, in particular at the considerable saturation of samples, which positively influences the precision of the pre-compaction stress measurement. Dawidowski et al., (2003) when investigating the model samples proved that the pre-compaction stress value measured in the unconfined conditions (the diameter of the loading plate is lower than the diameter of the deformed sample) is higher. Śnieg et al., (2008) and Błażejczak (2009), found out that determination of the pre-compaction stress at the considerable soil saturation (corresponding to the water potential which is pF2) in the confined conditions (the diameter of the loading plate is similar to the diameter of the sample), may lead to obtaining raised values of this parameter.

Differences in the conditions of water flow in deformed samples are among possible factors which influence the determined pre-compaction stress. In the case when soil samples are loaded in the confined conditions, when the diameter of the loading plate is close to the internal diameter of the ring, the soil flow is impeded through the ring wall which in the conditions of considerable saturation of the sample with water may negatively affect the course of the soil deformation process. In the conditions of possible expansion of the deformed soil when the diameter of the plate is lower than the diameter of the sample, water filtration is possible and its flow is limited less than in case of deformation made in the confined conditions. It has not been determined so far what should be the proportion between the diameter of the loading plate and the ring in order to limit the impact of the water filtration processes in the deformed samples and other parameters which define the soil properties on the value of the determined pre-compaction stress.
Objective, scope and methods of research

The objective of this paper was to verify the impact of the plate diameter on the value of the determined pre-compaction stress of soil with maintaining fixed dimensions of the ring (cylinder). The scope of the research covered determination of the soil moisture impact on the relation between the value of the determined pre-compaction stress and the plate diameter and determination of the range of diameters of plates for which no impact of their changes on the pre-compaction stress values, regardless the soil moisture, is observed.

Investigations were carried out on the model samples produced of the soil material collected from the subsoil located 35-40 cm in depth in the rural area (site) of Nowy Przylep (Zachodniopomorskie Voivodeship). Typical properties of the soil material were determined. The textural group determined with Bouyoucos-Casagrande's method in Prószyński's modification (sand fractions were washed on the sieve with meshes dimension of 0.1 mm). A pycnometer method was used for determination of the solid phase density. The humus content was measured with Tiurin's method and the soil reaction with the electrometric method. The plastic limit was measured with the rolling method and the liquid limit with the use of Cassagrande's apparatus.

Production of model samples consisted in sieving of the moist material through the sieve with 6 mm diameter and then in uni-axial compaction in stiff steel rings (cylinders) with the internal diameter and height of 100 and 30 mm respectively. Such or similar sizes of cylinders referred particularly to their internal diameter are often used in the research on the pre-compaction stress of soil (Mosaddeghi et al., 2007a; Mosaddeghi et al., 2007b; Rücknagel et al., 2007; Krümmelbein et al., 2008). Quantity of the soil material was selected in order to obtain the volumetric density of the model samples similar to the density of...
samples with the so called intact structure, determined in these soils during previous field research (Błażejczak et al., 2010). The produced samples were then loaded with a testing machine with plates of the varied diameters: 20, 30, 50, 70, 80, 90, 96, 98 and 99 mm. Loading was carried out in five iterations for each diameter. The registered courses of the unit pressure (stress) made by the plates from deformation of samples were used for determination of their pre-compaction stress ($NG$), for which the value was measured with the so-called linear regression method also called the classic method in geotechnology (Izbicki and Stróżyk, 2008). The method of determination of the pre-compaction stress applied in this paper was presented in figure 1. The tests were carried out in two series of samples which differ with moisture. At the same time it was assumed that the moisture values should be similar to the maximum values of the moisture range observed in natural conditions during spring and autumn field works (Błażejczak and Dawidowski, 2013). Calculations were carried out in Excel and Statistica.

Results and analysis

Table 1 presents results of determination of own properties of the soil material. It was silt loam (acc. to USDA – PTG 2009) with the neutral reaction ($pH_{KCl} = 6.34$) and average content of humus of 2.00%. This material was low compact – difference between the liquid ($L_L$) and plastic limit ($P_L$) was 9.9% of the moisture content.

Table 1.
Results of measurement of properties of the soil material in the 35-40 cm layer

<table>
<thead>
<tr>
<th>Content of particles with diameters (PTA 2009)</th>
<th>Specific density ($g\cdot cm^{-3}$)</th>
<th>Reaction (in KCl) ($pH$)</th>
<th>Humus content (%)</th>
<th>Plastic limit ($P_L$)</th>
<th>Liquid limit ($L_L$)</th>
<th>% w/w</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand ($2-0.05$)</td>
<td>Silt ($0.05-0.002$)</td>
<td>Loam (&lt;0.002)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>53</td>
<td>11</td>
<td>2.46</td>
<td>6.34</td>
<td>2.00</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>31.2</td>
</tr>
</tbody>
</table>

Present moisture of the produced model samples of the first and second series were at the average respectively: $w_1=13.7$ and $w_2=21.9\%$ water moisture content. The average values of dry density of solid particles of samples with the moisture of $w_1$ and $w_2$ were respectively: 1.47 and 1.54 $g\cdot cm^{-3}$. The comparison of the model samples moisture in both series and the value of the plastic limit prove that $w_1=0.64P_L$ a $w_2=1.02P_L$. The calculated degrees of saturation of samples with the moisture of $w_1$ and $w_2$ were respectively: 0.49 and 0.96.

Figure 2 and 3 present average courses of the unit pressure in relation to deformation of soil samples for various diameters of compaction plates. One may notice that they have varied courses, mainly for samples whose moisture is $w_2$ (fig. 3) whose value was close to the plastic limit of soil.
The impact of the plate...

Figure 2. Average shape of the unit pressure course of plates with varied diameters from deformation of samples for the soil water content of \( w_1 = 13.7\% \)

Figure 3. Average shape of the unit pressure course of plates with varied diameters from deformation of samples for the soil water content of \( w_2 = 21.9\% \)
For the samples with moisture of $w_1$ (fig. 2) the impact of the changes of the plate diameter on the shape of experimental curves was relatively small and thus the differences between the determined values of the pre-compaction stress were not high (fig. 4). It is also proved that by, inter alia, a small value of the coefficient of determination ($R^2$). However, the negative impact of the diameter of the plate on the pre-compaction stress value is noticeable. It was also reported that the dispersion of results of the pre-compaction stress values was higher for the lowest diameter ($d_{20}$), and clearly the highest for the biggest diameters of plates ($d_{80}$, $d_{90}$, $d_{96}$, $d_{98}$, $d_{99}$). A bigger dispersion of the pre-compaction stress values in case of diameter $d_{20}$ may be justified with the fact that along with the decrease of the plate diameter the processes taking place in the zone of impact of its edges may have even bigger share in the soil compaction resistance. The ratio of the plate diameter to its surface area was from 0.04 (for $d_{99}$) to 0.20 (for $d_{20}$). For the plate with the diameter $d$ smaller than $D$ (internal diameter of the ring) in the zone of the impact of its edges soil sheering takes place which is accompanied (according to the actual state of knowledge) with chaotic internal friction between the soil particles. In case of the biggest plates the explicit impact of the cylinder wall takes place which is related to the external friction, whose chaotic course may affect the range of the obtained results of the pre-compaction stress. The phenomena which take place on the edge of the plate also justify slightly higher values of the pre-compaction stress for small plates which are obtained for the moisture $w_1$ in comparison to the biggest ones. For small plates for which the participation of internal friction in the samples compaction resistance is higher than in case of the biggest plates, the determined pre-compaction stress has a higher value because the angle of the internal friction at the low soil moisture ($w_1=0.64P_L$) assumes high values. In case of plates from $d_{80}$ to $d_{99}$ for which the participation of internal friction forces which occur in the impact zone of the plate edges in the resistance of samples compaction decreases along with the increase of the diameter and external friction occurs, the pre-compaction stress $NG$ has a lower value because the angle of external friction at the low soil moisture assumes low values (Domżał et al., 1978). The reduction of the pre-compaction stress in case of samples with the moisture $w_1$ for the biggest plates cannot be justified with the impact of filtration water along the wall of the cylinder because its impact was not reported, which on the other hand was taking place during deformation of samples with moisture $w_2$.

A clearly varied course of experimental curves for the samples whose moisture is $w_2$ (fig. 3) had a considerable impact on the determined value of the pre-compaction stress of soil (fig. 5). The relation between $NG$ and the plate diameter was parabolically non-linear with the minimum value obtained for the diameter of the plate close to 50 mm. The initial stabilization of $NG$ values and then their increase along with the increase of the plate diameter above 50 mm is noticeable. Such course of relations may be justified with slowing of air and water filtration in the deformed samples along with the increase of the diameter of the used plate. The result in this case undermines the justification of using the uniaxial test of samples compression in laboratory in confined for determination of the pre-compaction stress value. In the field conditions when pores are not entirely saturated with water, there is a possibility of water filtration outside the zone of load impact.
The impact of the plate...

Figure 4. Value of the pre-compaction stress in relation to the plate diameter for the samples with soil water content of \( w_1 = 13.7\% \)

Figure 5. Value of the pre-compaction stress in relation to the plate diameter for the samples with soil water content of \( w_2 = 21.9\% \)

In order to select the range of diameters where the size of the applied plate does not affect the value of the determined pre-compaction stress, a single factor analysis of variance with post-hoc Tukey's test was applied. Division into uniform groups was carried out at \( \alpha = 0.05 \). Based on the results of this analysis one may notice (tab. 2) that for samples with the moisture of \( w_1 = 0.64P_L \) no significant impact of the diameter of the used plate on the determined value of the pre-compaction stress of soil was reported. All NG values were included to the same uniform group. In all samples with moisture \( w_2 = 1.02P_L \) four uniform
groups of the pre-compaction stress were distinguished. Analysis of the relation of \( d/D \) to the diameter of the cylinder \( (D) \) may lead us to the assumption that \( d/D \leq 0.7 \) of the pre-compaction stress \( NG \) values do not differ significantly. But for \( d/D \geq 0.30 \) the pre-compaction stress values are slightly higher than for \( d/D = 0.50 \) and \( d/D = 0.70 \). For \( d/D = 0.80 \) of the pre-compaction stress values may be considered as temporary and for \( d/D > 0.80 \) their stabilization at the raised level was reported. It is noticeable that for \( d/D = 0.90 \) and \( d/D = 0.96 \) the pre-compaction stress values are the highest and then they drop. It may be justified with the fact that the samples deformation for the value of \( d/D \) which are close to 0.90 is accompanied by water and air filtration outside the deformed zone and soil shearing on the plate circumference (internal soil friction). Additionally, soil particles adhering to the internal wall of the cylinder as a result of adhesive forces are not transported by the plate but pressed thereto. These factors cause the raise of the registered resistance of the sample compaction. On the other hand, the increase in the plate diameter to the value of \( d/D \geq 0.98 \) caused that adhesive forces between soil particles and the cylinder wall are battled and the phenomenon of the external friction and the filtrating water along the cylinder wall causes its moistening and as a result the soil compaction resistance decreases.

Table 2.
The pre-compaction stress values at the moisture of \( w_1 \) and \( w_2 \) for particular plate diameters divided into uniform groups

<table>
<thead>
<tr>
<th>Moisture</th>
<th>Plate diameter (mm)</th>
<th>Pre-compaction stress (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>( w_1 )</td>
<td>237a</td>
<td>261a</td>
</tr>
<tr>
<td>( w_2 )</td>
<td>109ab</td>
<td>109ab</td>
</tr>
</tbody>
</table>

Notice: small letters define uniform groups at \( \alpha = 0.05 \)

Conclusions
1. For samples made of the soil material with the granulation type of the loam silt and the moisture of 0.64 of their plastic limit value, the calculated pre-compaction stress \( (NG) \) does not significantly depend on the plate diameter (at \( \alpha = 0.05 \)) used for soil deformation. But for the ratio of the plate diameter \( (d) \) to the cylinder \( (D) \) equal to 0.2 or \( \geq 0.8 \) an increased range of measured values of the pre-compaction stress is noticeable.
2. For samples with the increased moisture close to their plastic limit value \( (w = 1.02P_L) \), the calculated pre-compaction stress value may significantly depend (at \( \alpha = 0.05 \)) on the plate diameter used for soil deformation. A clear difference of the value of the determined pre-compaction stress in noticeable in relation to the ratio of the plate diameter \( (d) \) to the cylinder \( (D) \), because results for \( d/D < 0.8 \) differed significantly from the ones obtained for \( d/D > 0.8 \).
3. The obtained research results allow the statement that in case of measuring the value of the pre-compaction stress of soil with the use of cylinders with the diameter of \((D)\) which is 100 mm the ratio \(d/D\) should be within \(0.3 \leq d/D < 0.8\).

4. Generalization of the obtained research results into other soil types and other dimension of samples requires further research.

References


WPŁYW ŚREDNICY STEMPLA NA WYZNACZANĄ WARTOŚĆ NAPRĘŻENIA GRANICZNEGO PRÓBEK WYTWORZONYCH Z GLEBY PYLASTEJ

Streszczenie. Celem pracy było zbadanie wpływu średnicy stempla na wartość wyznaczanego naprężenia granicznego gleby. Badania przeprowadzono na próbkach modelowych o średnicy 100 mm i wysokości 30 mm, wytwarzanych z materiału glebowego o uziarnieniu pyłu gliniastego i wilgotnościach 13,7 oraz 21,9% wag. Oznaczono następujące cechy użytego materiału: skład granulometryczny, gęstość fazy stałej, zawartość próchnicy, odczyn, granicę plastyczności i płynności oraz obliczono stopień wilgotności próbek. Wytworzone próbki były obciążane za pomocą maszyny wytrzymałościowej stemplami o średnicach: 20, 30, 50, 70, 80, 90, 96, 98 i 99 mm. Wartość naprężenia granicznego gleby wyznaczano metodą poszukiwania punktu przecięcia stycznych do krzywej naprężeń wtórnych i krzywej naprężeń pierwotnych (metoda klasyczna). Stwierdzono, że dla próbek o wilgotności równej 13,7 % wag. naprężenie graniczne nie zależy istotnie od średnicy stempla. Dla próbek o wilgotności 21,9% wag. naprężenie graniczne może zależeć istotnie od średnicy stempla. Na podstawie uzyskanych wyników sformułowano wniosek, że w badaniach naprężenia granicznego metodą jednoosiowych odszczelnić stosunek średnicy stempa (d) do średnicy cylindra (D) powinien mieścić się w przedziale 0,3 ≤ d/D < 0,8.

Słowa kluczowe: gleba, naprężenie graniczne, metodyka, warunki odkształcania