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THE INFLUENCE OF THE AGE-HARDENING OF SILTY LOAMY SAND ON ITS STRENGTH DETEMINING BY PRE-COMPACTION STRESS

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ABSTRACT

The influence of age-hardening of silty loamy sand soil on its strength, characterised by pre-compaction stress, was investigated. Soil samples were uniaxially moulded in steel rings at water contents 11, 15, 19% w/w by preloading up to 1.35, 1.45, 1.55 $g \cdot cm^{-3}$. Obtained pre-compacted samples were stored in sealed plastic bags at constant water content. Later, after approximately 0.1, 8, 24, 72, 144 h, samples were removed from the bags and reloaded. The obtained strain-stress relationships were used for calculation of pre-compaction stress values. Presented experimental results show the significant increase in soil strength within a few days after the soil samples were preloaded.

Key words: soil, pre-compaction stress, age-hardening

INTRODUCTION

The mechanical strength of soil plays an important role in agriculture. Arable soils have to be sufficiently weak for tillage activities, and at the same time they have to be sufficiently strong to carry wheel loads.

The strength properties of soil are changing with time after straining. When a previously undisturbed soil is being deformed, the soil particles move relative to each other and the bonds between particles become broken. Thus, in this case, the strength of recently disturbed soil is lower than that of undisturbed one, even when the soil bulk density has not been changed [4]. If, after the disturbance, the soil is kept at constant density and water

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content, it is usually found that some or all of the original strength is regained [1, 4, 5, 6, 7, 8, 9, 10]. In literature this effect is called variously, as age-hardening, curing, strength regain, or thixotropy. Mitchell [7] defined thixotropy as an isothermal, reversible, time dependent process, taking place under conditions of constant composition and volume, whereby a material stiffens while at rest, and softens or liquifies when remoulded. Therefore the term thixotropic hardening is used if the conditions of the system meet Mitchell's definition. In other cases the term age-hardening is used. Two main mechanisms have been observed, which can contribute to age-hardening of soils: particle rearrangement (type A) and particle-particle cementation (type B) [4]. An important difference between type A and B is the different relation to compaction pressure [2, 4].

In investigations of the age-hardening process the thixotropic strength ratio (the strength at time t divided by the initial strength – t = 0) is used, in order to permit comparisons between soils of different composition, or between samples of the same soil but of different water contents [4, 7, 10]. In these cases the absolute strength increase may be misleading.

In this paper the results of the influence of the age-hardening of silty loamy sandy soil on its pre-compaction stress are presented.

MATERIALS AND METHODS

Soil. The soil material was taken from horizon A_p-on forest-meadow chernozem site Pyrzyce, situated around Szczecin in northwestern Poland. Some details of this soil are given in table 1.

Table 1. Some physical and chemical properties of the soil material

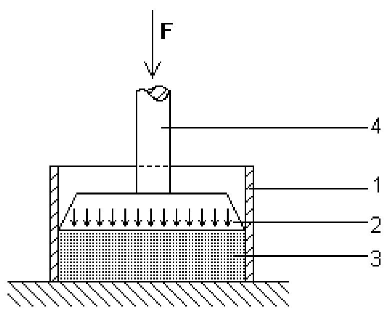
Soil type	horizon	Texture, %*			Organic carbon, %	pH	Plastic limit, %
		Sand	Silt	Clay			
Chernozem, loess	Ap	47	40	13	1.23	7.2	19.1

***Sand – 0.063-2 mm, silt – 0.002-0.063 mm, clay < 0.002 mm**

Experimental procedure. The air-dried soils were ground to < 2mm, wetted to 3 different water contents (11, 15 and 19% w/w) and stored in tightly closed plastic bags for 4-6 days, to allow redistribution and equilibration of the added water through the whole soil mass.

Next the soil was preloaded in steel rings of 51 mm radius and 50 mm height, up to bulk density 1.35, 1.45, 1.55 $g \cdot cm^{-3}$, to get artificial samples of height of 25 mm (fig. 1). For this each ring was filled with a calculated amount of soil, according to initial water content and assumed bulk density of preloaded soil core. The soil cores were replicated four times for each water content and density. The stresses applied at initial preloading were related to expected sample density and ranged between 46-393 kPa. The obtained soil cores were stored in airtight plastic bags at temperature 17-19°C (in room) and were shaded from the light.

Figure 1. Confined compression test:
1 – steel ring, 2 – compression plate,
3 – soil, 4 – piston, F – force



Approximately 0.1, 8, 24, 72, and 144 h after preparing, the moist soil cores were removed from the bags and reloaded by pressing them with increasing force F up to height of 23 mm. The obtained sinkage-stress relationships were used for determination of the threshold value of soil pre-compaction stress. The computerised method was used to determine the value of pre-compaction stress [3].

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RESULTS AND DISCUSSION

In the experiment it has been shown that the pre-compaction stress distinctly increases with soil age-hardening (time of sample storing). These changes of the pre-compaction stress P_o versus time t of ageing are presented on figures 2 and 3 (left side), for different initial water content and soil bulk density.

Figure 2. Pre-compaction stress Po and strength increases ratio S/So for silty loamy sand for different bulk density (1.35, 1.45,1.55g·cm^{-3}) as a function of time t since compaction at 11; 15; and 19% water content (% w/w)

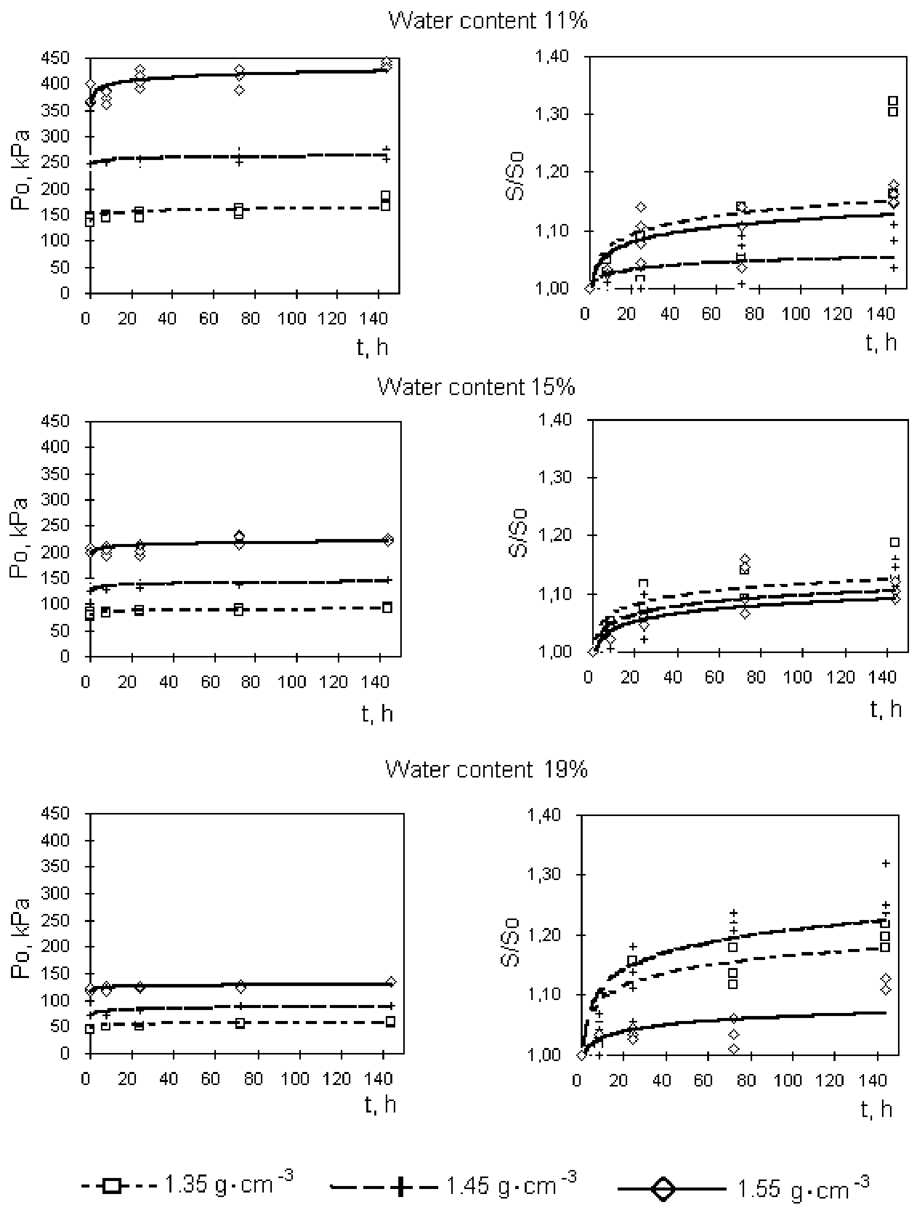

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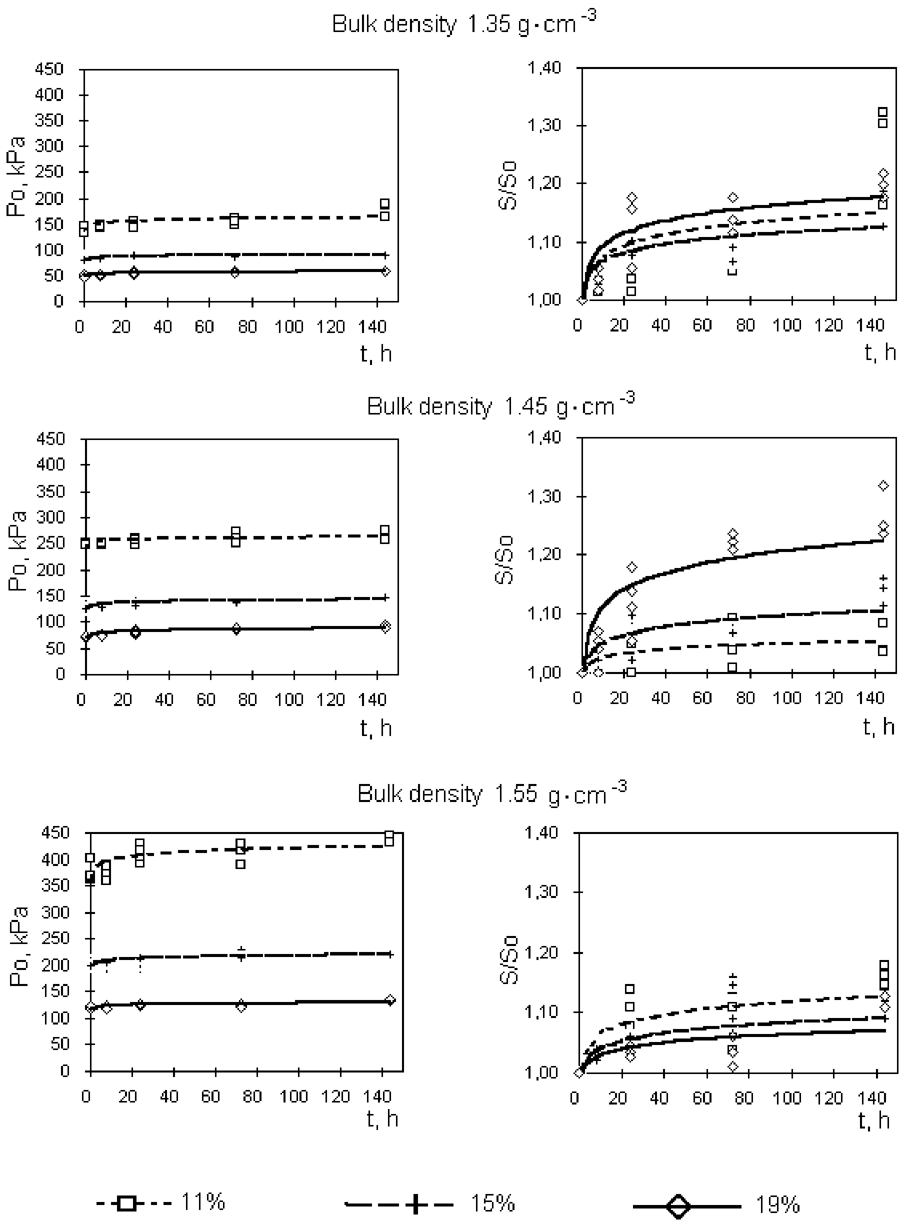
Figure 3. Pre-compaction stress Po and strength increases ratio S/So for silty loamy sand for different water content (11, 15, 19% w/w) as a function of time t since compaction at 1.35, 1.45 and 1.55g·cm^{-3} bulk density



Relationship between pre-compaction stress and time of sample storing has been described by logarithm equation:

$$P_o = a_0 + a_1 \cdot \ln(t) \qquad (1)$$

where, a_0 and a_1 are adjustable parameters. The values of the parameter a_0 were close to the pre-compaction stress of freshly remoulded (preloaded) sample at time $t \approx 0$. The parameter a_1 can be considered as a gradient of the pre-compaction stress change with time t (in hours). The values of the adjustable parameters a_0, and a_1, including the square of correlation coefficient (R^2) for the curve fit, are given in table 2. It can be seen that the pre-compaction stress of remoulded samples (coefficient a_0) decreased with increase of water content. On the other hand, high bulk density had a positive effect on the threshold value of soil pre-compaction stress of soil, irrespective of water content. The change of the value of soil pre-compaction stress (value of regression coefficient a_1) was influenced remarkable not only by ageing time, but also by initial soil condition – bulk density and water content.

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Table 2. Values of a_0 and a_1 of equation 1, the square of correlation coefficient R^2 for the curve fit

Water content % w/w	Bulk density $g \cdot cm^{-3}$	a_0 kPa	a_1 $kPa \cdot h^{-1}$	R^2 -
11	1.35 1.45 1.55	142 249 377	4.21 2.63 9.57	0.46 0.42 0.59
15	1.35 1.45 1.55	82 129 200	1.75 2.70 3.94	0.69 0.56 0.44
19	1.35 1.45 1.55	50 73 120	1.55 3.00 1.81	0.74 0.76 0.46

To find whether the influence of initial soil conditions on soil pre-compaction stress is significant or not the equation (1) was transformed into the linear form as follows:

$$P_o = a_0 + a_1 \cdot t^*, \qquad (2)$$

where $t^* = \ln(t)$. Results of analysis of variances of regression coefficients (a_1), presented in table 3 and 4, shown that the significance of the influence of initial soil conditions on age soil strengthening is also dependent upon the relation between density and moisture of the soil.

Table 3. Results of statistical analysis of variances of regression coefficients a_1 (equation 2) for different bulk density (1.35, 1.45, 1.55$g \cdot cm^{-3}$) at constant water contents (11, 15, 19% w/w)

Water content % w/w	Value of regression coefficient a_1 for different bulk density $g \cdot cm^{-3}$			$F_{Calc.}$	F_{Tabled} (α = 0.05)
	1.35 $g \cdot cm^{-3}$	1.45 $g \cdot cm^{-3}$	1.55 $g \cdot cm^{-3}$		
11	4.21	2.63	9.57	7.39*	3.18
15	1.75	2.70	3.94	2.22	3.19
19	1.55	3.01	1.81	3.98*	3.20

***significant difference**

Table 4. Results of statistical analysis of variances of regression coefficients a_1 (equation 2) for different water contents (11, 15, 19% w/w) at constant bulk density (1.35, 1.45, 1.55$g \cdot cm^{-3}$)

Bulk density ($g \cdot cm^{-3}$)	Value of regression coefficient a_1 for different water content			$F_{Calc.}$	F_{Tabled} (α = 0.05)
	11%	15%	19%		
1.35	4.21	1.75	1.55	4.59*	3.19
1.45	2.63	2.70	3.01	0.11	3.18
1.55	9.57	3.94	1.81	8.40*	3.19

***significant difference**

In order to permit comparisons between soil samples behaviour at different water content and bulk density, the thixotropic strength ratio S/S_o, called also as the strength increase ratio, was used (figures 2 and 3, right side). S_o is the initial threshold value of soil pre-compaction stress, determined directly after the sample was preloaded, and S is the strength determined on soil sample after a certain ageing period. Relationship between the thixotropic strength ratio S/S_o and time of sample storing has been also described by logarithm equation (see equation 1). The maximum value of the thixotropic strength ratio S/S_o, calculated from pre-compaction stress determined for 0.1 h and 144 h stored soil samples, varied in average from about 1.05 to 1.35. It means that successive tillage operations should be spaced by several days to protect the soil against damaging of its structure. Thus also soil compactibility can be reduced with time at given soil conditions.

The identification of type of mechanism of age-hardening can give information about strength regain e.g. in the seedbed [2, 4]. As can be seen from the figure 2 (right side), at water content of 19% values of S/S_o do depend significantly on initial sample density. In this particular case the age-hardening soil behaviour was therefore

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similar to what is described in literature as soil particle rearrangement (type A) [4]. For 11 and 15% of water content values of S/S_o do not depend significantly on sample initial density.

According to Utomo and Dexter [9] the optimum water content for the largest age-hardening is around the lower Plastic Limit. For the Pyrzyce soil the Plastic Limit was 19.1 % w/w. It can be seen from figure 3 (right side) that the largest intensity of soil age-hardening for this soil has been observed at 19% of water content, in particular at bulk density of 1.45 $g \cdot cm^{-3}$, and not so significant at 1.35$g \cdot cm^{-3}$. It means that the maximum ageing effect was obtained near the optimum water content for tillage, i.e. just below the plastic limit.

CONCLUSIONS

1. The effect of age-hardening of soils can be determined by means of the pre-compaction stress, which distinctly increases with soil age-hardening.
2. The influence of water content and bulk density on age-hardening is remarkable. A high water content has a positive effect – for soil used in this experiment (silty loamy sand) the effect of age-hardening process (values S/S_o) increased at water contents around the Plastic Limit (19% w/w) at low and medium levels of soil compaction (1.35 and 1.45 $g \cdot cm^{-3}$). It was also found that high bulk density (1.55 $g \cdot cm^{-3}$) had a negative effect on the age-hardening in terms of thixotropic strength ratio (values S/S_o).
3. The use of different levels of soil bulk density in studies of age-hardening effects (different intensities of compaction pressures) is a useful tool which makes possible to identify the type of mechanism age-hardening phenomena. The identification of the type of mechanism age-hardening phenomena with the confined compression test can give information about strength regain of soils.

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