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Structural change in aggregated soils during the compaction process based on variations in initial structure

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Introduction

Initial structure plays a decisive role in soil compaction behaviour. In aggregated soils there are signs that density heterogeneity is of particular relevance for precompression stress and settlement behaviour.

For this reason, the aim is to pursue the question of how dry bulk density, aggregate density and the aggregate density/dry bulk density ratio (AD/BD ratio) change during the compaction process.

Materials und methods

Test sites

- Warin (Northern Germany): Sandy Loam (590 g kg^{-1} sand, 100 g kg^{-1} clay)
- Görzig (Central Germany): Silt Loam (220 g kg^{-1} sand, 240 g kg^{-1} clay)

Each test site includes a long-term tillage experiment with the variants "Plough" (tillage depth 25 cm) and "Cultivator" (tillage depth 8-15 cm).

Soil core sampling, compression tests and aggregate density

In each case, soil core samples (diameter 100 mm, length 28 mm) were extracted from the topsoil (soil depth 15-22 cm). After collecting the soil, the samples were saturated and then adjusted to a matric potential of -6 kPa in a sand box. Only one loading step was applied to each individual soil core in a fully automatic oedometer (drained conditions). We used five (Görzig site) and eight (Warin site) loading steps (5, 16, 50, 160, 500 kPa and 5, 10, 25, 50, 100, 200, 350, 550 kPa respectively), with three (Görzig site) and six (Warin site) replications. After each loading step (180 minutes), a relaxation phase (15 minutes) was included.

After each compression was performed, the soil samples were taken apart and aggregates of 8-10 mm in size were obtained. The determination of aggregate density according to RÜCKNAGEL et al. (2007) was carried out using these. The AD/BD ratio was calculated as the quotient of aggregate density and dry bulk density. It is a yardstick for the expression of the inter-aggregate pore system and thus also for the density heterogeneity within the soil structure.

The stress/bulk density functions of whole soil and aggregates were analysed separately, and these served to help numerous independent testing persons determine precompression stress using CASAGRANDE's graphical method (1936).

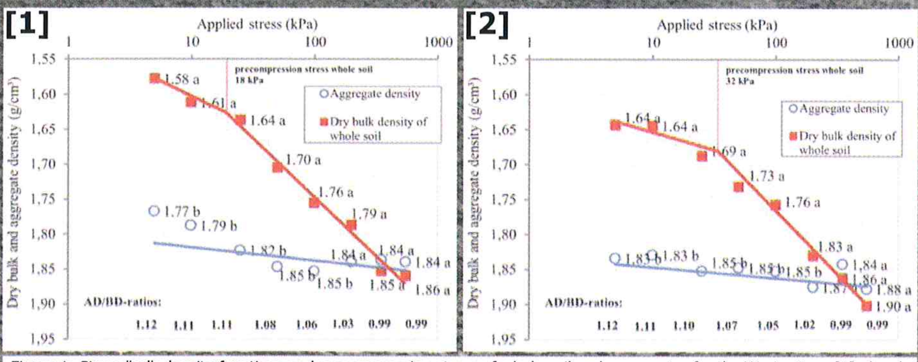

Figure 1: Stress/bulk density functions and precompression stress of whole soil and aggregates for the Warin site – [1] plough variant, [2] cultivator variant (different small letters indicates significant differences between dry bulk density and aggregate density at the same load step ($p<0.05$)).

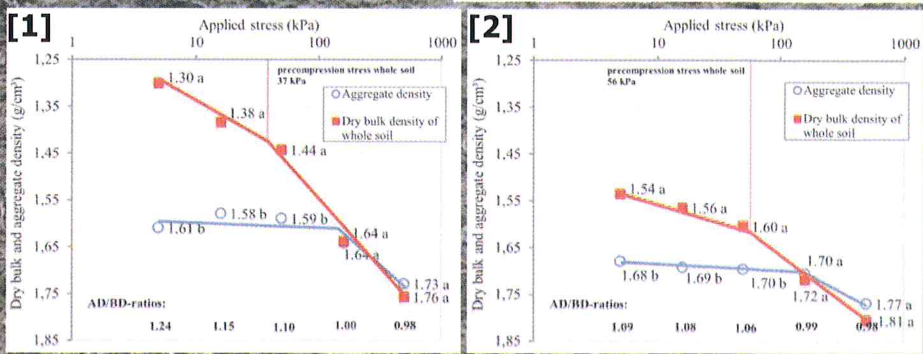

Figure 2: Stress/bulk density functions and precompression stress of whole soil and aggregates for the Görzig site – [1] plough variant, [2] cultivator variant (different small letters indicates significant differences between dry bulk density and aggregate density at the same load step ($p<0.05$)).

Results and discussion

At both sites, and for each of the tillage variants, the stress/bulk density functions of the whole soil follow the typical development for over-consolidated soil (Fig. 1 and 2). When precompression stress is exceeded, the re-compression section – which demonstrates only a slight increase in dry bulk density – is followed by a more pronounced plastic deformation in the virgin compression section. Overall, the precompression stress values of the whole soil are low (18-56 kPa). The cultivator variants do, however, demonstrate slightly higher precompression stress than the plough variants. In Görzig, the higher precompression stress levels for the cultivator variants can be explained by the considerably closer AD/BD ratio, and in Warin by the higher dry bulk density for a comparable AD/BD ratio in the initial structure.

The stress/aggregate density functions present a different picture. At the Warin site, they follow an almost linear pattern. Here, aggregate density increases only slightly between the lowest and the highest loading step. Precompression stress cannot be determined. At the Görzig test site, aggregate density for the highest loading step does at least demonstrate a clear increase compared to the values for lower stress levels. Here, too, it is not possible to reliably calculate precompression stress. It can however be presumed that its value lies somewhere between the final two loading steps (160-500 kPa). Thus it lies considerably above the precompression stress levels of the whole soil.

All of the variants examined have in common that aggregate density and dry bulk density equal each other in the highest loading steps. As a measure of density heterogeneity, up to the precompression stress level of the whole soil the AD/BD ratios decrease only slightly, and beyond it they reduce quite considerably, reaching a value of approximately 1.0 (completely closed aggregate arrangement) at the highest loading steps.

CASAGRANDE, A. (1936): The determination of pre-consolidation load and its practical significance. In: Int. Conf. on Soil Mech. and Found. Eng. Proc. of ICSMFE. Cambridge, MA, 22-26 June 1936. vol. 3. Cambridge, MA, 93-108.
RÜCKNAGEL, J., HOFMANN, B., PAUL, R., CHRISTEN, O. & K.-J. HÜLSBERGEN (2007): Estimating precompression stress of structured soils on the basis of aggregate density and dry bulk density. Soil & Tillage Research 92, 213-220.

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