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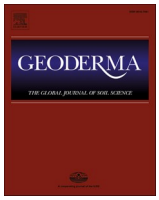

Impact of calcareous concretions on soil shrinkage of a Vertisol and their relation model development

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ABSTRACT

Shajiang black soil (Vertisol) has a high shrinkage capacity and contains many calcareous concretions (CC). We assume the volume of CC to be rigid during wetting and drying cycles. Thus, the soil containing CC may have different shrinkage behavior from that of fine soils (without CC). We aimed to quantify the effects of CC content and size on soil shrinkage behavior, as well as to develop a model to characterize the relationship among the void ratio (e), moisture ratio (υ), and solid volume of CC (Csv) in Shajiang black soil. Four different sizes (2–5, 5–10, 10–20 and, 20–30 mm) of the CC at a rate of 10% on mass, and four different contents (0, 5%, 10%, and 20% on mass) of 5–10 mm CCs were mixed into the fine soils to prepare the CC-soil mixtures. Our results showed that the increasing CC content significantly reduced the saturated void ratio (e_s), coefficient of linear extensibility (COLE), and shrinkage index of all pores except the medium pores ($P < 0.05$), but the CC size did not. The shrinkage curves of the CC–soil mixtures were proportional to that of the fine soil, which was modified by the portion of CC volume in the CC–soil mixtures. We proposed a new numerical equation based on Peng and Horn shrinkage model (2005) to illustrate the relationship among e– υ –Csv. The shrinkage curve of the CC–soil mixture was predicted well ($R^2 = 0.95$–0.98) by the new model based on that of fine soil and the CC volume modification. However, the proposed model underestimated the volume change for the dry side of the shrinkage curve, in which the swelling and shrinkage of fine soil matrix among CCs were partially concealed. Our work demonstrates that the CC in the Shajiang black soil does not change soil shrinkage behavior except the modification of void ratio, and thus its shrinkage curve can be estimated from that of the non-CC soil. It can be concluded that this study provides a useful model for estimating the shrinkage behavior of soils containing rigid coarse inclusions.

1. Introduction

Calcareous concretions (CC), as special coarse inclusions, are extensively dispersed in soils across the world as a result of soil formation processes and human activities. In China, they mainly exist in the Calcic Vertisol, which covers a region of around 4 million ha in North China plain (Li et al., 2011). The CC can be regarded as a major component and typical feature of soil configuration. Previous researches (Chen et al., 2020; Gu, 2018; Wei, 2017) reported that the CCs are all found along the top 100 cm profile with a larger concentration in 20–60 cm soil layer, which can be up to 0.44 g g^{-1}. Large pores at the interface between CCs and fine soils can be easily formed during wetting and drying cycles (Gargiulo et al., 2015). However, the reorganization of the pore system during drying cannot be fully reflected in soil deformation when high content of CCs exists. Thus, the presence of CC complicates the relationship between soil structure and soil moisture.

Due to the high clay content and the presence of montmorillonite minerals, the Calcic Vertisol has a significant swelling and shrinkage capacity (Wang et al., 2021). According to the study of Zong (2013), the average coefficient of linear extensibility (COLE) of this type of soil in China is up to 0.099, with a high shrinkage level. Soil shrinkage and swelling, related to changes in soil structural properties as a result of changes in hydraulic stress, can be described by a soil shrinkage curve (SSC). The SSC typically comprises four distinct phases: structural, proportional, residual, and zero shrinkage (Braudeau et al., 2004; Cornelis et al., 2006; Peng and Horn, 2005; Peng and Horn, 2013). The

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