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Quantifying the Soil Swelling Potential by Soil Water Isotherm

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Swelling potential has long been used as a terminology to quantitatively describe the expansibility of soil. It encompasses multiple definitions such as the swelling pressure under specific strain constraints or the free swelling strain without confining stress. However, although these definitions are of great significance to engineering practice, they do not directly represent the physical nature of soil expansion. Resistance to mineral swelling occurs due to Van der Waals and Coulomb forces between crystal layers. The water adsorption ability within the interlayer space of expansive minerals can overcome this resistance by enabling water molecules to enter the interlayer space, resulting in macroscopic soil expansion. The interlayer hydration of expansive minerals serves as the intrinsic reason for soil swelling. Therefore, the authors propose utilizing the energy available for swelling of the interlayer space under a specific humidity as the soil swelling potential. To experimentally determine the proposed swelling potential, a framework based on the soil water isotherm (SWI), which establishes the constitutive relation between relative humidity and water content, was developed. SWI not only represents the energy state of soil water but also captures the interlayer water content change of expansive soil during wetting and drying through its hysteresis at low humidity. By leveraging the existing SWI model, which determines interlayer water content, and the method of calculating the water adsorption ability of soil (referred to as soil sorptive potential, SSP) using SWI, the authors can quantify the proposed soil swelling potential under any humidity. Several verifications were conducted to validate the proposed swelling potential. Firstly, the SWI of montmorillonite was generated using molecular simulation, combined with basal spacing measurements obtained from XRD tests under varying humidity. The interlayer water content and system energy change from the molecular simulation were analyzed to understand the volume change of mineral during wetting and drying. The energy change of soil-water system under humidity variations was used to verify the theoretical soundness of the established swelling potential framework. Secondly, the measured SWIs of different soil samples were utilized to calculate the swelling potential of these soils, thereby confirming the practical feasibility of the proposed framework. Finally, to facilitate comparison with existing indicators for identifying expansive soils, the energy used for crystal layer expansion during the water adsorption process, which can also be calculated using the proposed framework, was defined as the swelling potential index. This index exhibited superior performance in identifying expansive soils compared to other indicators of soil swelling ability. This study offers a novel perspective on the study of expansive soils and establishes a scientific basis for understanding the engineering behaviors of expansive soil under varying humidity environments.

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