

# Unitary Definition of Matric Suction

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Matric suction or negative matric potential (unit: kilopascal) is the free energy change in a unit volume of water when isothermally transferred from the soil water state to the free water state, and is defined at the soil-water-air representative elementary volume (REV) [Fig. 1(a)]. Matric suction has been widely considered as the most fundamental physical variable governing unsaturated soil behavior such as effective stress, shear strength, swelling pressure, freezing temperature depression, and thermal conductivity. Nevertheless, the prevailing definition of matric suction ( $\psi_m$ ) as negative capillary pressure or the pressure difference between pore air ( $u_a$ ) and pore water ( $u_w$ ) still bears incomplete physics

$$\psi_m = u_a - u_w \quad (1)$$

The complete physical mechanisms involve capillarity and adsorption (e.g., Lu and Likos 2004). Eq. (1) only holds under the existence of capillary water and overlooks the local pressure variation due to the existence of adsorptive water, which can account for more than 30% of the gravimetric water content ( $w$ ) in some expansive soils (e.g., Lu and Likos 2004). To incorporate adsorption, the augmented Young–Laplace (AYL) equation (e.g., Philip 1977) is proposed to define matric suction

$$\psi_m = -C(\kappa) - \Pi(h) \quad (2)$$

where  $C = \text{capillary pressure} - (u_a - u_w)$ , and is a function of air–water interface curvature  $\kappa$ ; and  $\Pi$  is the disjoining pressure due to van der Waals interaction between soil and water, and is a function of adsorptive water film thickness  $h$ . Physically, the AYL equation is established at the REV of the air–water film [Fig. 1(b)], and thus is unable to describe the varying thermodynamic states within the REV or at other locations inside soil water body.

Adsorption in soil physically originates from the electromagnetic fields generated not only by van der Waals forces but also by electrical double layers, exchangeable cations, and surface hydroxyls. These adsorptive forces are generated outside the soil water body and have been recently combined into a concept called soil sorptive potential (SSP) (Lu and Zhang 2019). The SSP ( $\psi_{\text{sorp}}$ ) is defined as the free energy change per unit volume of soil water at the inter-water molecular scale REV [Fig. 1(b)] resulting from interaction with the soil matrix. Accordingly, the local energy equilibrium at any point in a soil water body with a water content  $w$  leads to

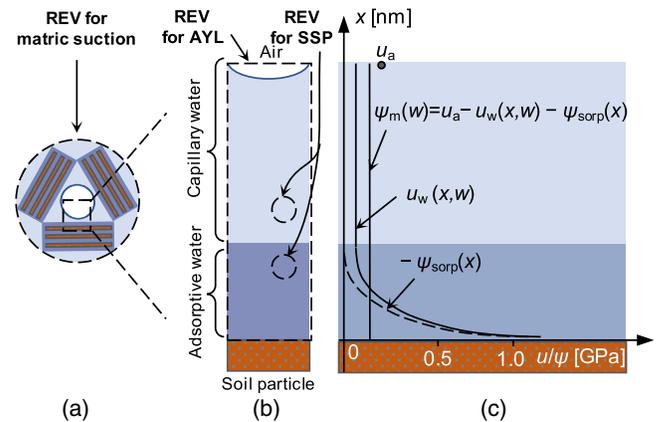
$$\psi_{\text{sorp}}(x) = u_a - u_w(x, w) - \psi_m(w) \quad (3a)$$

$$\psi_m(w) = u_a - \gamma_w h_m(w) = u_a - u_w(x, w) - \psi_{\text{sorp}}(x) \quad (3b)$$

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**Fig. 1.** (a) REV for matric suction; (b) REVs for AYL and SSP; and (c) pore-water pressure, matric suction, and SSP profiles.

where  $\gamma_w = \text{unit weight of water}$ ; and  $h_m = \text{matric potential head}$ . Both quantities are defined at the scale of matric suction REV. Variable  $x$  is the statistical distance to a particle surface.

Eq. (3a) states that the SSP is a spatially varied intrinsic property of the soil matrix, and it always converts to mechanical energy [ $u_w(x, w)$ ] and matric suction [ $\psi_m(w)$ ]. The unitary definition of matric suction [Eq. (3b)] can fully describe the pore water pressure variation at every point in a soil water body, including in capillary water and adsorptive water, and at the air–water interface. The SSP can induce compressive pore water pressure (up to a few gigapascals) near the particle surface under both saturated and unsaturated conditions [Fig. 1(c)]. Eq. (3b) can be reduced to Eq. (1) in capillary water [where  $\psi_{\text{sorp}}(x)$  vanishes] or to Eq. (2) for the air–water film REV [where  $\psi_{\text{sorp}}(x) = \Pi(h)$ ].

## Implications

The SSP is recognized as a missing piece in linking matric suction and local pore water pressure. The latter, not the former, is the thermodynamic state variable dictating a wide array of fundamental phenomena in clayey soils such as abnormally high soil water density (up to 1.6 g/cm<sup>3</sup>), supercooling (down to −22°C), and depressed cavitation. The unitary definition of matric suction provides a general basis for defining pore water pressure, effective stress, and phase transition behavior in soil, and calls for reassessment of theories based on defining  $u_a - u_w$  or negative capillary pressure as matric suction.

## References

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