# Unsaturated Soil Mechanics: Fundamentals, Behaviour & Engineering Applications

## Important Notes

# 1. What is Unsaturated Soil?

In nature, most soils above the water table exist in an unsaturated state - their pores contain both water and air simultaneously.

| Saturated | Unsaturated |
|---|---|
| Pores fully filled with water. Classic geotechnics applies. | Pores contain air + water. Three-phase system with suction. |

- The three phases are: solid grains, pore water, and pore air - each with its own pressure.
- Most natural slopes, embankments, pavements, and expansive soils are unsaturated during dry periods.
- Classical effective stress concepts (Terzaghi) do not directly apply - a new framework is needed.

## 2. Matric Suction Fundamentals

Matric suction is the difference between pore-air pressure and pore-water pressure. It is the primary variable governing unsaturated soil behaviour.

**Equation:** $\psi = u_a - u_w$ where $u_a$ = pore-air pressure, $u_w$ = pore-water pressure

- Suction ranges from 0 kPa (saturated) to >1,000,000 kPa (oven-dry).
- Total suction = Matric suction + Osmotic suction (from dissolved salts).
- Higher suction → stronger soil. Rainfall reduces suction → triggers instability in slopes.

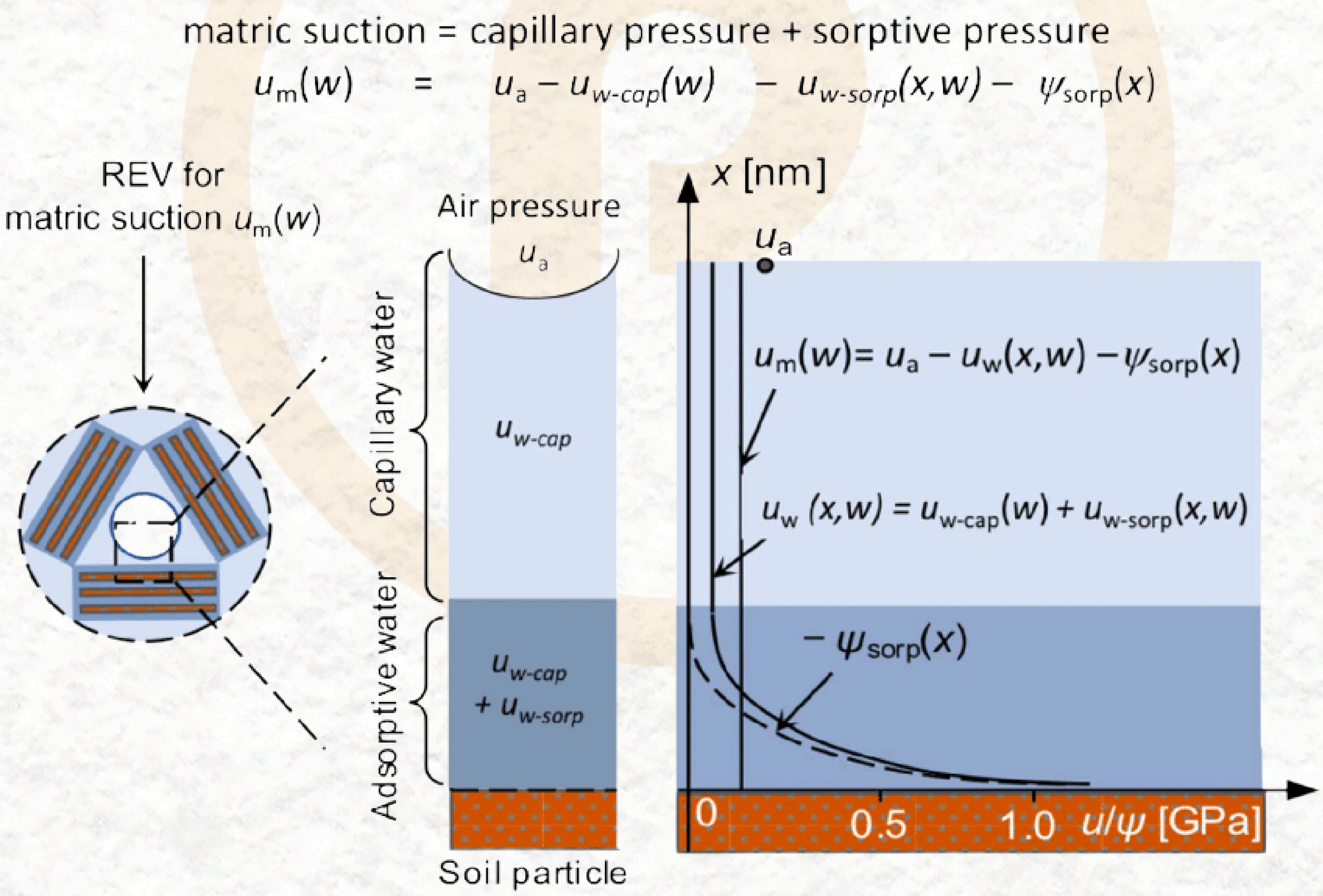


**Figure:** Illustration of generalized matric suction definition. **Source:** **RESEARCHGATE**

# 3. Soil Water Characteristic Curve (SWCC)

The SWCC defines the relationship between water content (or degree of saturation) and matric suction. It is the most fundamental constitutive relationship in unsaturated soil mechanics.

| AEV | Hysteresis |
|---|---|
| Air-Entry Value — suction at which air first enters pores. | Wetting & drying paths differ due to ink-bottle effect. |

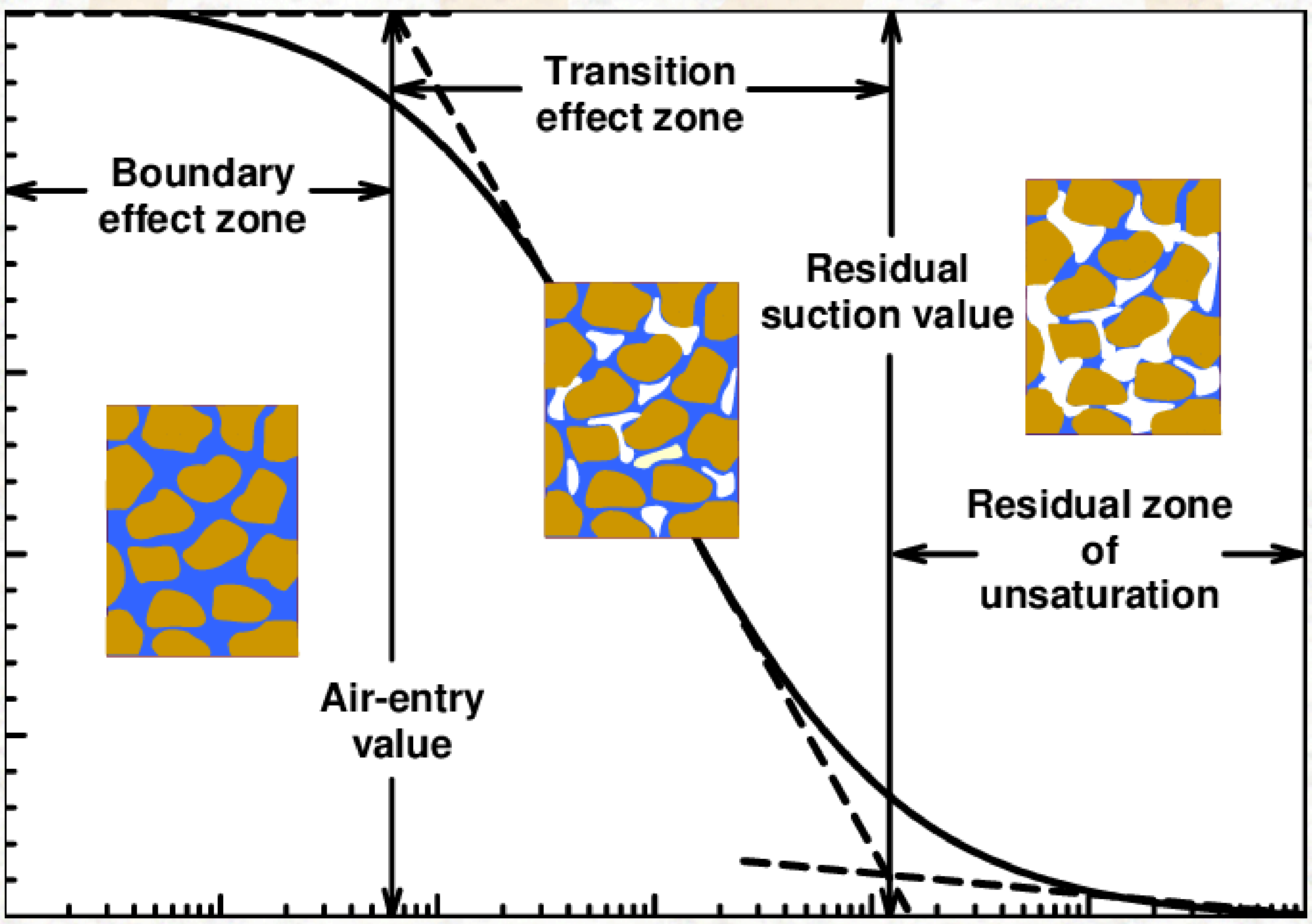


**Figure:** SWCC showing different zones of unsaturation **Source:** **RESEARCHGATE**

# 4. Measuring Suction: Lab & Field

**Laboratory Methods**

| Tensiometer | Pressure Plate |
| --- | --- |
| Direct pore-water pressure measurement. Range: 0–80 kPa. | Axis translation technique. Ideal for SWCC construction. |

| Chilled Mirror | Filter Paper |
| --- | --- |
| Measures total suction via dew-point hygrometry. | Simple & low-cost. Calibrated relationship used for suction. |

**Field Methods**

- *Jet-fill tensiometers and Watermark sensors for near-surface monitoring.*
- *TDR (Time Domain Reflectometry) measures volumetric water content indirectly.*

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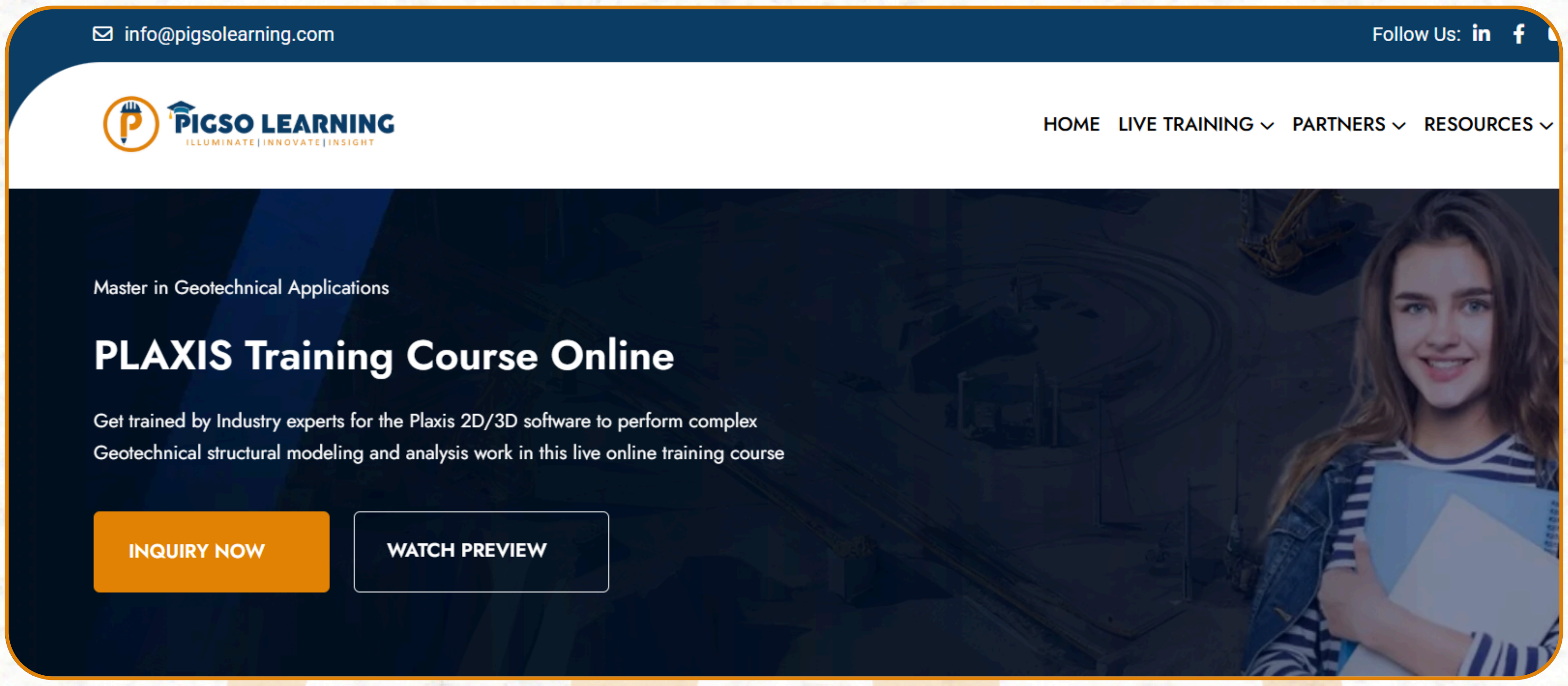


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# 5. Shear Strength of Unsaturated Soils

Fredlund et al. (1978) extended the Mohr-Coulomb criterion using two independent stress state variables to describe unsaturated shear strength.

**Equation:** $\tau = c' + (\sigma - u_a) \tan \varphi' + (u_a - u_w) \tan \varphi^b$ $c'$ = effective cohesion, $\varphi'$ = friction angle, $\varphi^b$ = suction friction angle

- $\varphi^b$ is typically 10°–25°, always less than or equal to $\varphi'$.
- As suction increases, apparent cohesion grows - unsaturated soils can stand at steeper angles.
- The SWCC and shear strength are intimately linked — both depend on degree of saturation.

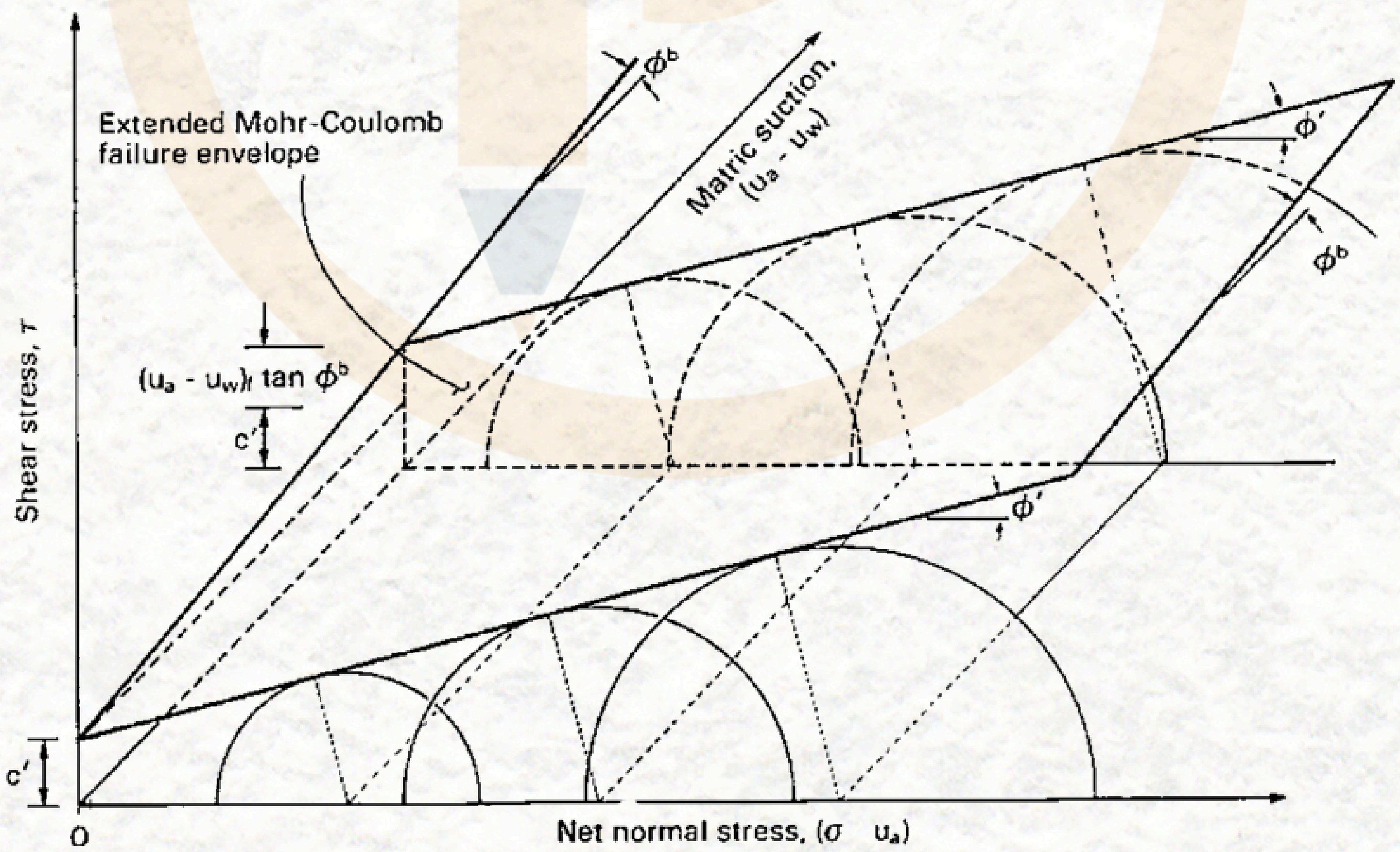


**Figure:** Mohr- Coulomb failure envelope for unsaturated soil **Source:** **RESEARCHGATE**

# 6. Stress State Variables & Effective Stress

Two independent stress state variables govern the mechanical behaviour of unsaturated soils - replacing the single effective stress of saturated mechanics.

| Net Normal Stress | Matric Suction |
|---|---|
| $(\sigma - u_a)$ — Controls deformation and yielding of the soil skeleton. | $(u_a - u_w)$ — Controls water retention and apparent stiffness. |

- Bishop's single effective stress χ approach: $\sigma' = (\sigma - u_a) + \chi(u_a - u_w)$, where $\chi$ = degree of saturation.
- The two-variable framework (Fredlund & Morgenstern) is more widely used in practice for its theoretical clarity.

# 7. Volume Change & Collapse Behaviour

Wetting an unsaturated soil can cause sudden, irreversible volume reduction - known as collapse. This is a major hazard in loessic and compacted soils.

| Swelling | Collapse |
|---|---|
| Expansive clays absorb water → volume increases. Common in arid regions. | Metastable open fabric collapses on wetting under load. |

- Collapse potential is highest in loosely compacted fills or aeolian deposits with low initial water content.
- The Hydro-Compression (HC) test measures collapse potential by inundating a loaded oedometer sample.
- Volume change is captured using the SWCC alongside a constitutive model (e.g., BBM - Barcelona Basic Model).

# 8. Engineering Applications

*Unsaturated soil mechanics underpins the design and analysis of critical infrastructure where water content is variable and soils are rarely fully saturated.*

| Slope Stability | Embankments |
|---|---|
| Rainfall-triggered landslides modelled via suction loss during infiltration. | Compacted earth dams designed using unsaturated compaction curves & suction. |

| Foundations | Pavements |
|---|---|
| Heave & settlement prediction in expansive soils under seasonal cycles. | Subgrade stiffness linked to suction state for pavement design. |

***Tags:*** *SWCC modelling · Numerical seepage · Collapsible fills · Expansive clays · Landslide risk*

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