Should we teach unsaturated soil "effective stress" as a means of simplifying introduction to unsaturated soil mechanics?

Effective stress was Terzaghi's concept for saturated soils for isotropic or 1-D K_o loading.

Terzaghi (1936) stated: " The stresses in any point of a section through a mass of soil can be computed from the total principal stresses, σ_1, σ_2, σ_3, which act at this point. If the voids of the soil are filled with water under a stress, u_w, the total principal stresses consists of two parts. One part, u_w, acts in the water and in the solid in every direction with equal intensity. It is called the neutral (or pore-water) pressure. The balance $\sigma_1' = \sigma_1 - u_w$, $\sigma_2' = \sigma_2 - u_w$, $\sigma_3' = \sigma_3 - u_w$ represent an excess over the neutral stress, u_w, and has its seat exclusively in the solid phase of the soil. All the measurable effects of a change in shearing resistance are exclusively due to change in the effective stress, σ_1', σ_2', σ_3'. "

Over the years, others have laid on their own definitions and interpretations of Terzaghi's effective stress, but just how much license to interpret is appropriate on this front?

Should we teach unsaturated soil "effective stress" as a means of simplifying introduction to unsaturated soil mechanics?

Bishop (1959) Proposed "Effective Stress" $\sigma' = (\sigma - u_a) + \chi(u_a - u_w)$

"Effective Stress for Unsaturated Soils" gives the wrong impression to non-unsat geotechnical engineers and students because there is no unsat "equivalent" that preserves the concept of effective stress for saturated soils.

Kohgo et al. (1993, pg 58): "……the effective stress concept in unsaturated soils may not be the same as that in saturated ones. The original definition of effective stress in saturated soils requires that changes in volume and shearing strength of a soil are due exclusively to changes in effective stress. However, in unsaturated soils, effective stresses do not only play significant roles. The softening or hardening of soil skeleton sometimes plays a more significant role."

Khalili et al. (2004, pg 120) argue that nonrecoverable plastic deformations such as collapse can be readily described within an effective stress framework by defining the yield surface as a function of suction. They present the following assumptions and assertions in defining effective stress for unsaturated soils:

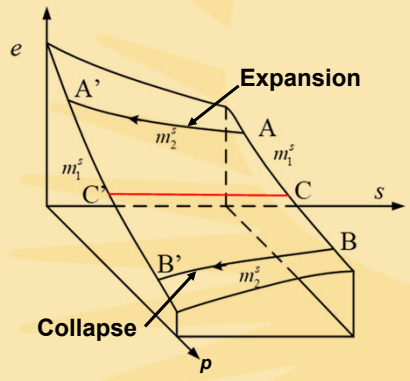
(1) The state of stress in a material is controlled by only the state of elastic straining.

(2) It is sufficient to show that the elastic response is uniquely controlled to demonstrate the effective stress principle.

(3) Only wetting and drying stress paths (at constant *p*) may be considered in validating the effective stress principle. stress paths considering change in net stress at constant suction need not be considered as in such cases a change in net stress is equal to a change in effective stress and therefore validity of effective stress is guaranteed a priori.

These assertions and assumptions make it clear that this unsaturated soils "effective stress" is different than Terzaghi's effective stress for saturated soils (i.e., the concept of Terzaghi's effective stress is changed).

3



Original State Surface Approach (modified from Matyas and Radhakrishna (1968))

Khalili, et al. also separate unsaturated soils as being: (1) collapsible, or (b) noncollapsible soils.

Any soil with clay can expand or collapse. Therefore, it is more general to use expansive zones and collapsible zones.

Soil response can be elastoplastic in both zones.

As noted by Kohgo et al. (1993) and Zhang and Lytton (2009, Modified State Surface Approach), the virgin loading state surface is the same as the elastoplastic surface.

This feature of the elastoplastic state surface is helpful in exploration of the question: *Should we use a Bishop's type "effective stress" to simplify introduction to unsaturated soil mechanics?*

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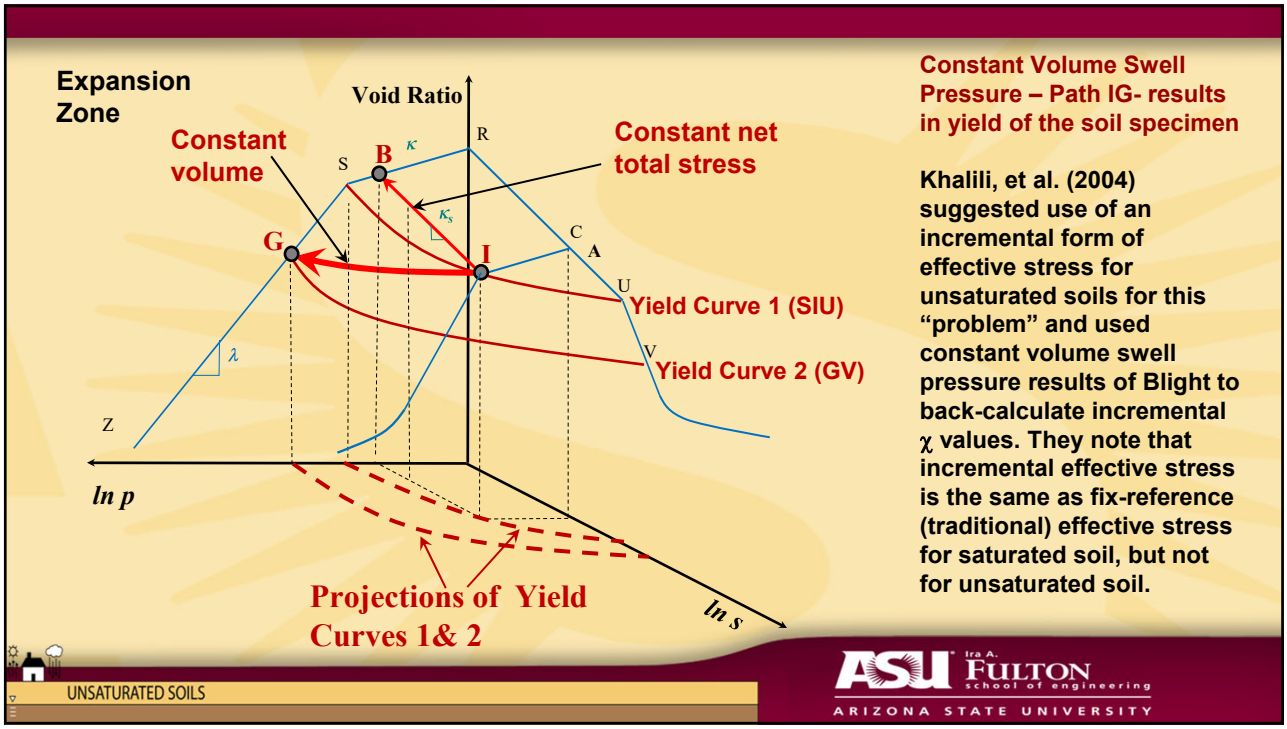

Constant Volume Swell Pressure – Path IG- results in yield of the soil specimen

Khalili, et al. (2004) suggested use of an incremental form of effective stress for unsaturated soils for this "problem" and used constant volume swell pressure results of Blight to back-calculate incremental χ values. They note that incremental effective stress is the same as fix-reference (traditional) effective stress for saturated soil, but not for unsaturated soil.

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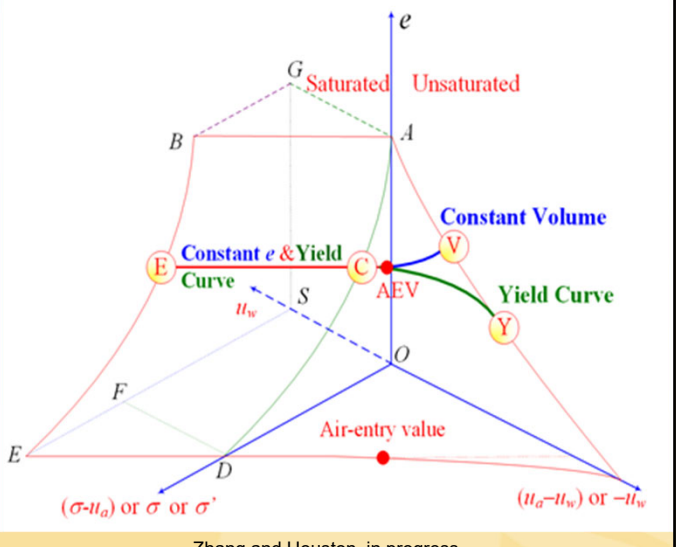
Modified State Surface Approach (MSSA) View for Isotropic Loading Showing Divergence of Constant Void Ratio and Yield Curves for Unsaturated Soil

For saturated soil constant volume and yield curves are coincident

No clear definition of "effective stress" for unsaturated soils exists.

A constant volume-based definition results in yield under constant "effective stress"

A no-yield based definition results in volume change under constant "effective stress"



Zhang and Houston, in progress

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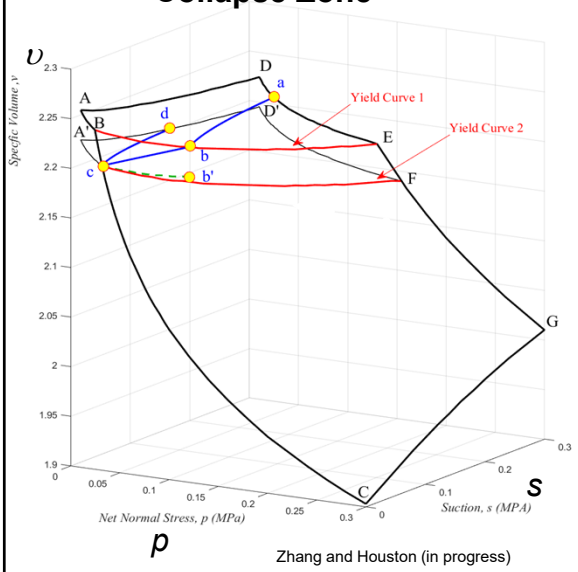
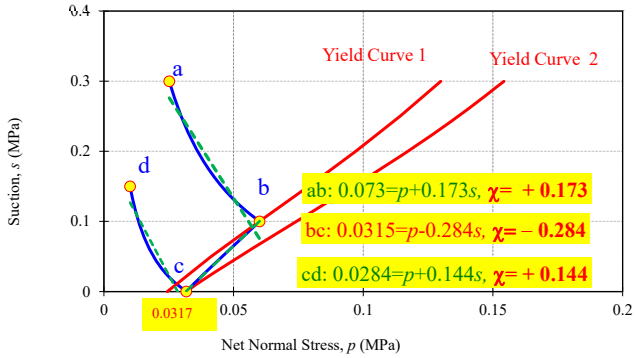
Collapse Zone



Zhang and Houston (in progress)

BBM prediction based upon Wheeler and Sivakumar (1995)



Constant Volume Paths:

ab – Wetting (e tends to increase, requiring increasing *p*), *elastic path*

bc – Wetting (e tends to decrease, requiring decreasing *p*), *elastoplastic*

cd – Drying (e tends to decrease, requiring decreasing *p*), *elastic*

In my experience undergraduates and most practitioners don't have any problem using uncombined stress variables of suction and net stress. A stress path type approach (in terms of *p* and *s*) can be used for unsaturated soils, allowing adoption of unsat into practice/education.

The unsat community searches for "effective stress" to "simplify" constitutive modeling and for smooth transition to the saturated state. It is debatable whether this is an "easier" path compared to improving separate *p* and *s* stress variable models (e.g., those outcropping from the BBM).

Unsaturated soil response is complex, requiring two separate stress variables. For saturated soils a single-valued effective stress is workable. However, it may be easier to also use separate saturated soil stress variables (σ and u_w) in problems where transitions from unsat to sat must be modeled. A combined effective stress and separated stresses for saturated soils yields the same result, so use of separated stresses for saturated soils is not a violation of Terzaghi's effective stress principle.

Unsaturated soils have complex elastoplastic behavior. We can simplify things for certain applications, certain regions of the problem and certain paths, but the foundational theory we present for the geotech community at large, and our students, must work for all of the primary problems of engineering interest.

Should we use Bishop's Type Effective Stress to ~~Simplify~~ Complicate Introduction of Unsaturated Soil Mechanics?

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Ira A. Fulton school of engineering
ARIZONA STATE UNIVERSITY

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