Unsaturated Soil Mechanics in Geotechnical Practice - Lessons Learned

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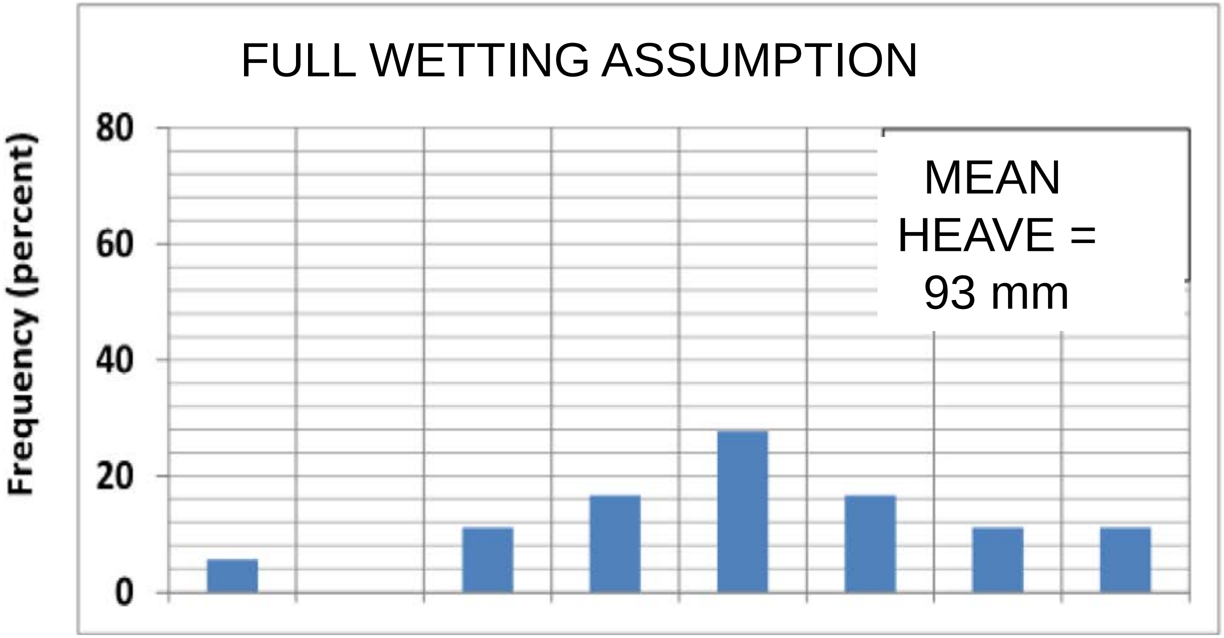
Why is Unsaturated Soils Important in Engineering Practice?

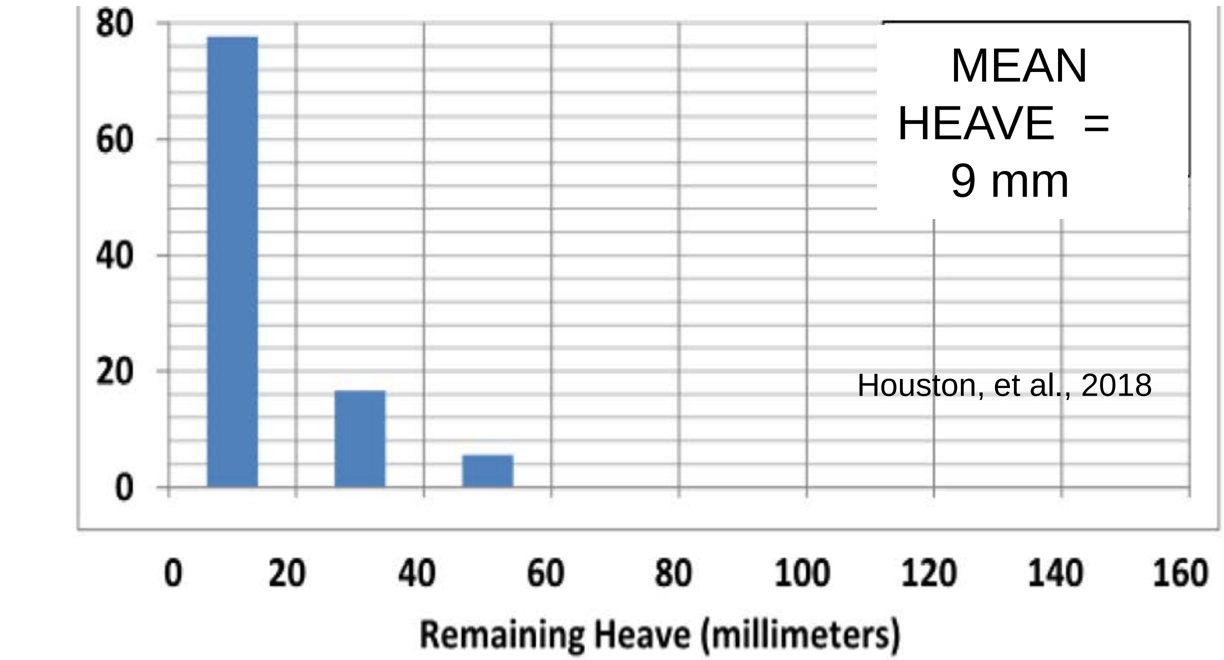
Slope Stability
Bearing Capacity and Settlement
Pavements
Deep Foundations
Collapsible Soils
Expansive Clays
Embankments and Dams
Retaining Walls ...

Following are a Few Examples

Why is Unsaturated Soil Mechanics Important in Geotech Practice? Heave Computations



USING BEST-ESTIMATE FIELD SUCTION PROFILES AND SURROGATE PATH METHOD (SPM)



REDUCTION OF AMOUNT OF HEAVE OF EXPANSIVE SOILS

Computation of Partial Wetting Swell Strain Using the SPM Interpolation (Houston and Houston, 2018)

1. R_w is defined as $R_w = (u_a-u_w)_f /(u_a-u_w)_i$

where $(u_a-u_w)_i$ =initial suction; $(u_a-u_w)_f$ =final suction.

R_w = 1 for no wetting; R_w = 0 for full wetting

$(1-R_w)$ = degree of wetting

2. Then, $\sigma_p = \sigma_{ob} + R_w (\sigma_{ocv} - \sigma_{ob})$

where σ_p = surrogate final total stress; σ_{ocv} = swell pressure;

and σ_{ob} = overburden stress (or overburden +structural).

3. The partial wetting swell strain is computed as:

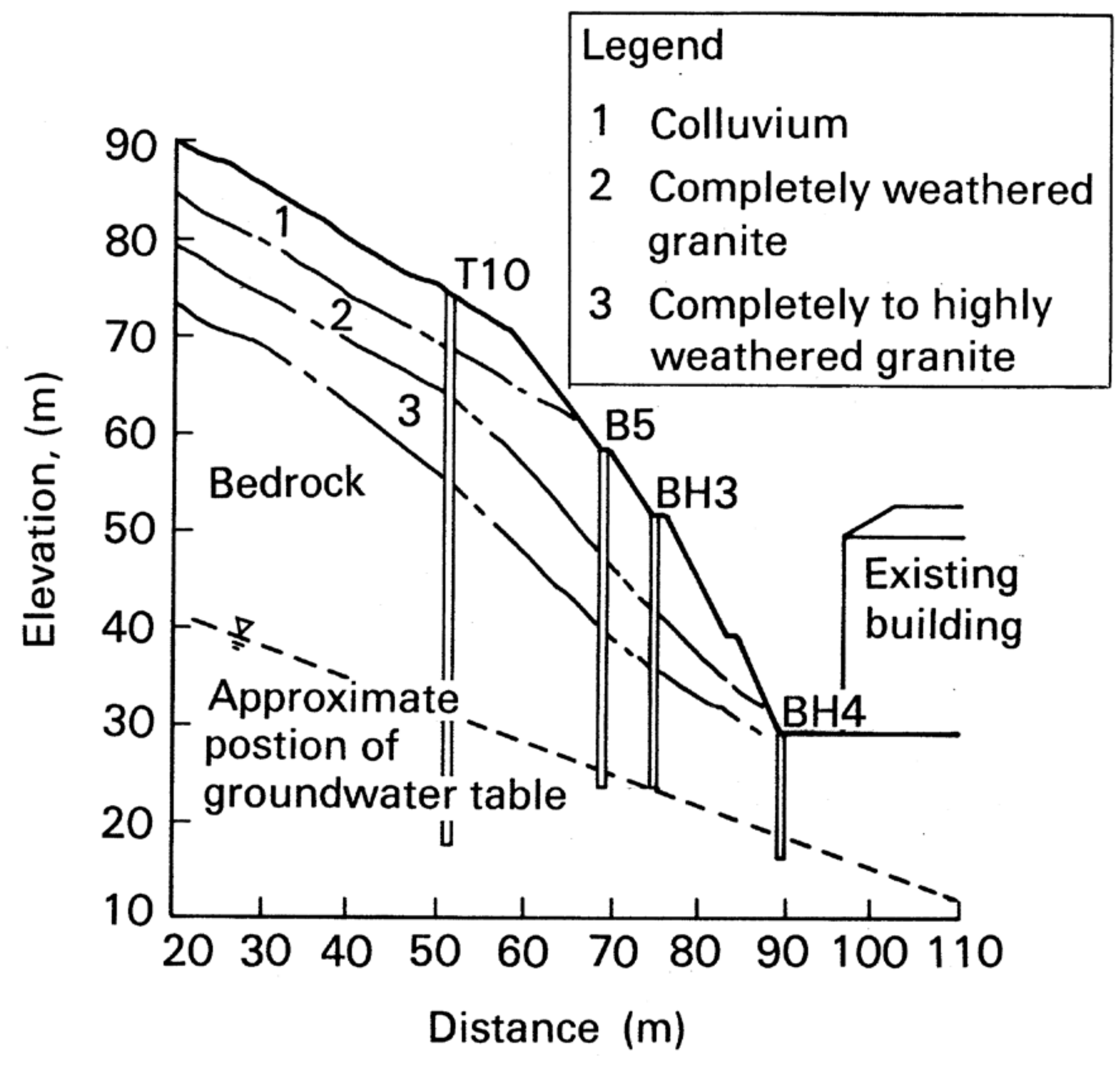
$$\varepsilon_{pw} = C_H \log (\sigma_{ocv}/\sigma_p)$$

where C_H =slope of the swell strain versus log σ plot obtained from fully wetted oedometer swell test (ASTM D4546)

Why is Unsaturated Soil Mechanics Important in Geotech Practice? Slope Stability

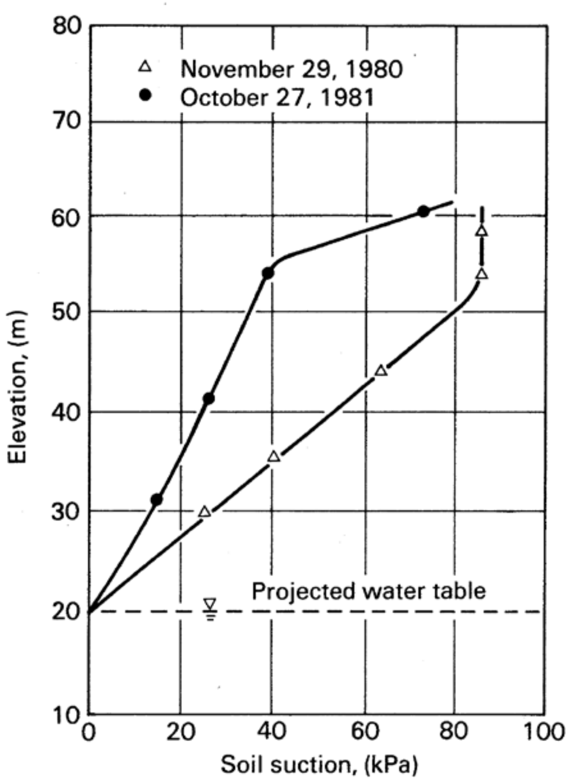
Case Study in Hong Kong (Fredlund, 1987)

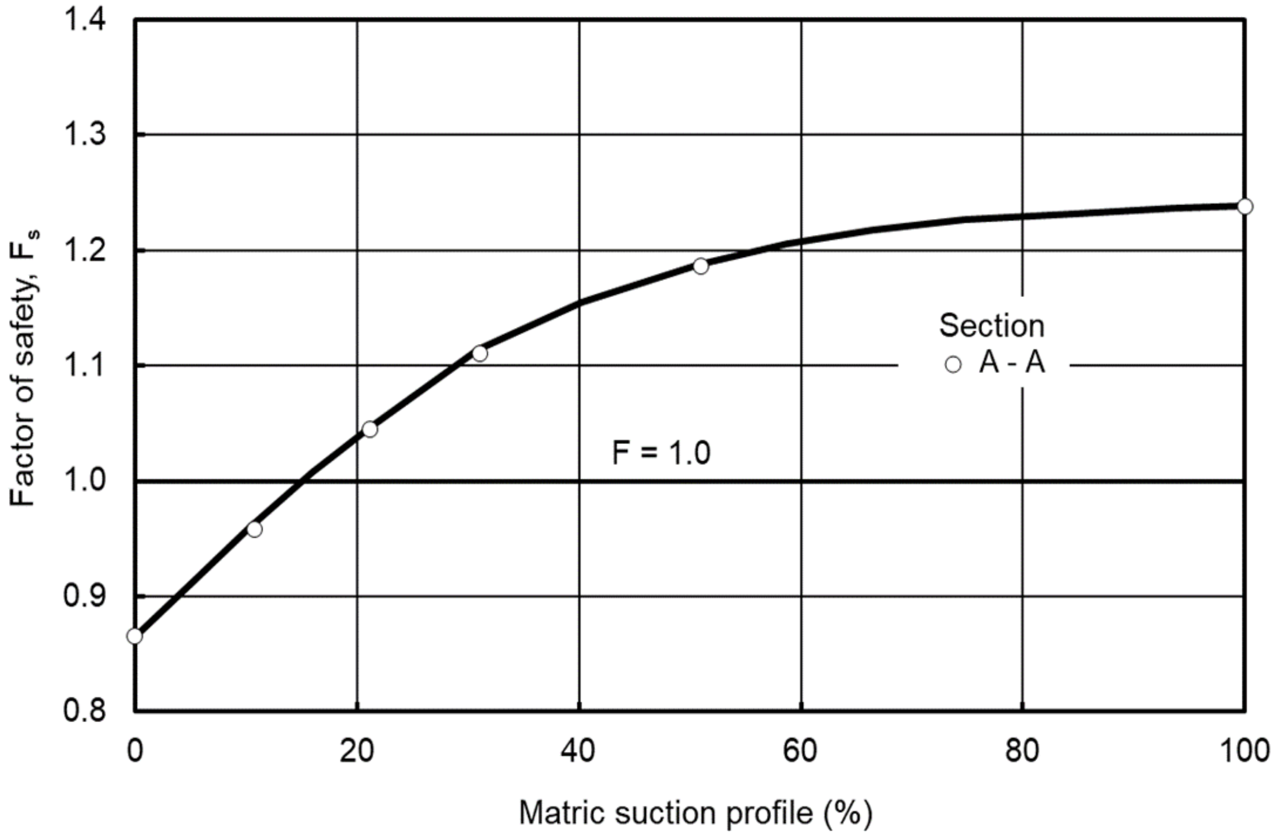
Proposed New Construction at Top of Slope Resulted in Evaluation of Stability. Using Saturated Shear Strength Data, the Existing Slopes were Found to have FS < 1.0 Even Prior to Addition of New Building.



FACTOR of SAFETY INCREASES WITH SUCTION

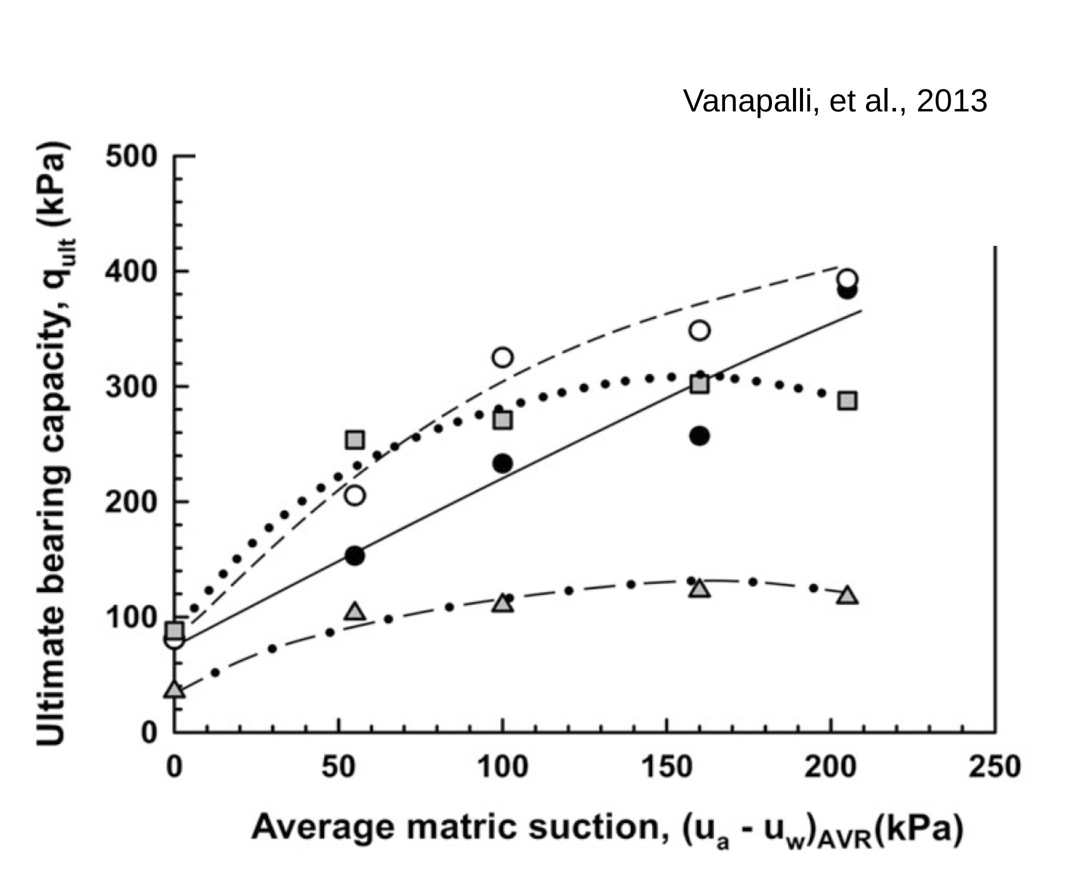
Why is Unsaturated Soil Mechanics Important in Geotech Practice? Slope Stability





Hong Kong Slopes (Fredlund, 1987)

Why is Unsaturated Soils Important in Engineering Practice? Bearing Capacity and Settlement of Foundations



Suction Increases Bearing Capacity

Suction Decreases Settlement of Footings

Effect of Partial Wetting on Shear Strength

For Slope Stability, Bearing Capacity, Retaining Walls, and Other Limit Equilibrium Problems

Shear Strength (Fredlund and Rahardjo 1993)

$$\tau_f = c' + (\sigma_n - u_a)tan\phi' + (s)tan\phi^b$$

where s = matric suction

$\sigma_n - u_a$ = net total stress

ϕ^b is angle for shear strength increase with matric suction

c' and ϕ' are effective stress parameters from (saturated tests)

Many Methods for Estimating ϕ^b

Example: Houston et al. (2008)

Below the air entry value (AEV), $\phi^b = \phi'$.

For suction higher than AEV (estimated from the SWCC) ϕ^b versus suction can be presented using a hyperbola:

$$a + b\Psi^* = \frac{\Psi^*}{\phi' - \phi^b}$$

where $\Psi^* = \Psi - AEV$

$a = f(D_{30}$ and $D_{60})$.

$1/b = \phi'$.

Measurement and Control of Soil Suction, 1940's and 1950s:

- Largely soil science (Richards, 1941; Hilf, 1956; Croney, 1952)

Unsaturated Soil Mechanics Theory, mostly 1960's to 1970's:

- **Role of soil suction in soil behavior**-Croney & Coleman (1948,1954,1960)
- **Conference on Pore Pressure and Suction in Soil**, London, 1961.
- **Suction Controlled Soil Tests**. Triaxial- Bishop and Donald (1961); Suction-Controlled Oedometer-Matyas and Radhakrishna(1968);Barden et al. (1969)

Laboratory testing was time consuming and technically challenging.

- **A "Single-value Effective Stress" for Unsaturated Soils** (Bishop, 1959; Croney, et al. 1958; Aitchison, 1961;Jennings, 1961)

$$\sigma' = (\sigma - u_a) + \chi(u_a - u_w)$$

A single-valued "effective stress" was shown to be inadequate for describing both volume change and shear strength behavior. The parameter χ was not degree of saturation and was not limited to a range of 0 to1. (Bishop & Blight, 1963, Jennings and Burland, 1962)

Unsaturated Soil Mechanics Theory, mostly 1960's to 1970's:

-Two "independent" stress state variables - an approach consistent with existing saturated soil mechanics methods (Matyas and Radhakrishna, 1968; Fredlund and Morgenstern, 1977; Gens, 1996; Wheeler and Karube, 1996).

$\sigma - u_a$ **Net Total Stress**

$u_a - u_w = s$ **Matric Soil Suction**

- Net Stress and Matric Suction were found to be effective in controlling the shear strength and volume change behavior of soils.

- There is no need to combine these two "net" stresses into one equation to solve engineering problems.

- In fact, NO SINGLE EQUATION IS NEEDED for stress state description – just directly use the two separate stress state variables of net total stress and matric suction.

Constitutive Model Development, 1970's to 1990's – and beyond: Models were developed to describe the behavior of unsaturated soils, mostly in terms of two stress state variables, σ-u_a and s. Constitutive models include piece-wise elastic; elasto-plastic, elasto-plastic hardening, …

Improved method of measurement of soil suction, 1990's and 2000's- and beyond: (Gee et al., 1992; Ridley and Burland, 1993; Leong, et al. 2003; Scanlon, 2002; Cobos, et al., 2017)

The 1990s and beyond have become a period where there has been an emphasis on the implementation of unsaturated soil mechanics into routine geotechnical engineering practice (Fredlund, 2006).

THE GEOTECHNICAL ENGINEERING PROFESSION HAS HAD A SOUND THEORETICAL BASIS FOR SOLVING UNSATURATED SOIL PROBLEMS FOR NEARLY **40 YEARS**.

HOW ARE WE DOING ON USE OF THE THEORY IN ROUTINE PRACTICE?

IMPLEMENTATION OF UNSATURATED SOIL MECHANICS IN GOTECHNICAL ENGINEERING PRACTICE - LESSONS LEARNED

The Role of:

- Educators
- Researchers
- Practitioners

The Role of

UNIVERSITY PROFESSOR

EDUCATORS

Introductory Geotech Class

http://www.mygovcost.org/2012/09/27/stuck-in-the-mud

What is Being Taught Today?

(Schidlovskaya and Briaud, 2016)

The emphasis in …. introduction to geotechnical engineering today is on:

1. **Laboratory tests such as classification, shear strength, consolidation, permeability.**
2. **Established theories such as consolidation for deformation, flow nets, Mohr circle and strength.**
3. **Saturated soils and a single effective stress variable.**

What was Being Taught In 1966?
(Bill Houston, 2018)

1. Laboratory tests such as classification, shear strength, consolidation, permeability.
2. Established theories such as consolidation for deformation, flow nets, Mohr circle and strength.
3. Saturated soils and a single effective stress variable.

50 years and little change in the Introduction to Geotech Classes!

POSSIBLE PATHS TO IMPROVEMENT

MORE CONFERENCES AND OPEN DISCUSSION ON GEOTECHNICAL ENGINEERING EDUCATION

DEVELOPMENT AND SHARING OF NEW COURSE MATERIALS FOR INTRODUCTORY GEOTECHNICAL ENGINEERING COURSES

OBTAIN PEER REVIEW COMMENTS ON COURSE MATERIALS

EXAMPLE

NEW MATERIALS FOR *INTRODUCTION TO GEOTECHNICAL ENGINEERING* ON THE TOPIC OF

STRESS STATE OF SOIL, STARTING WITH SOIL AS HAVING 3 MAIN PHASES

Funded Projects on Engineering Education

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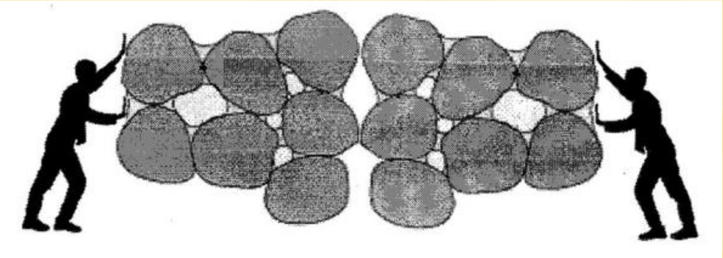
State of Stress of Soils

Because soil, in general, has 3 main phases (air, water, and solid), there are 3 stresses that must be considered in describing the overall state of stress:

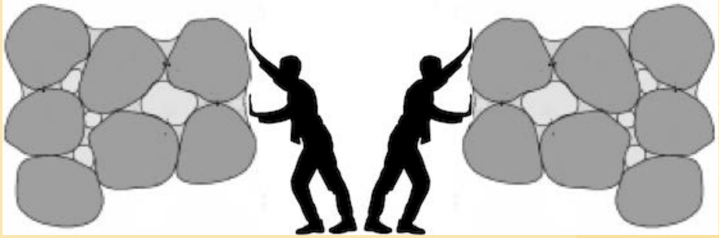
1. **total stress (σ)**
   - normally compressive
2. **pore air pressure (u_a)**
   - normally positive or zero
3. **pore water pressure (u_w)**
   - can be positive or negative, but is usually negative in the field when the soil is unsaturated and all three phases (solid, water, and air) are present.

Simplified View of State of Stress for Soil

- Total normal stress (σ) tends to push grains/particles together.



- Positive pore air pressure (u_a) tends to push grains/particles apart.



- Negative pore water pressure (u_w) tends to pull the grains/particles together

Stress State

It has been well-demonstrated that if we choose to combine these three stresses into two “net” stress state variables, we will have two variables that are **measurable**, and which can be **applied/controlled externally** to the soil, both of which tend to keep the grains/particles together.

1. The “net” total stress $(\sigma-u_a)$
2. The matric suction $(u_a-u_w) = s$

STATE OF STRESS OF THE SOIL

GEOTECHNICAL ENGINEERING FOR SOILS REQUIRES SIMULTANEOUS CONSIDERATION OF TWO SEPARATE STRESS STATE VARIABLES

THESE TWO STRESS VARIABLES ARE EFFECTIVE IN CONTROLLING SHEAR STRENGTH AND VOLUME CHANGE OF SOIL:

$\sigma - u_a$ **Net Total Stress**

s **Matric Soil Suction**

What Forces Act on Soils?

External Forces

- The combined weight of the soil and structures on it are examples of external forces.
- These forces, distributed over the area of a representative element of soil, results in what is called **total stress:**

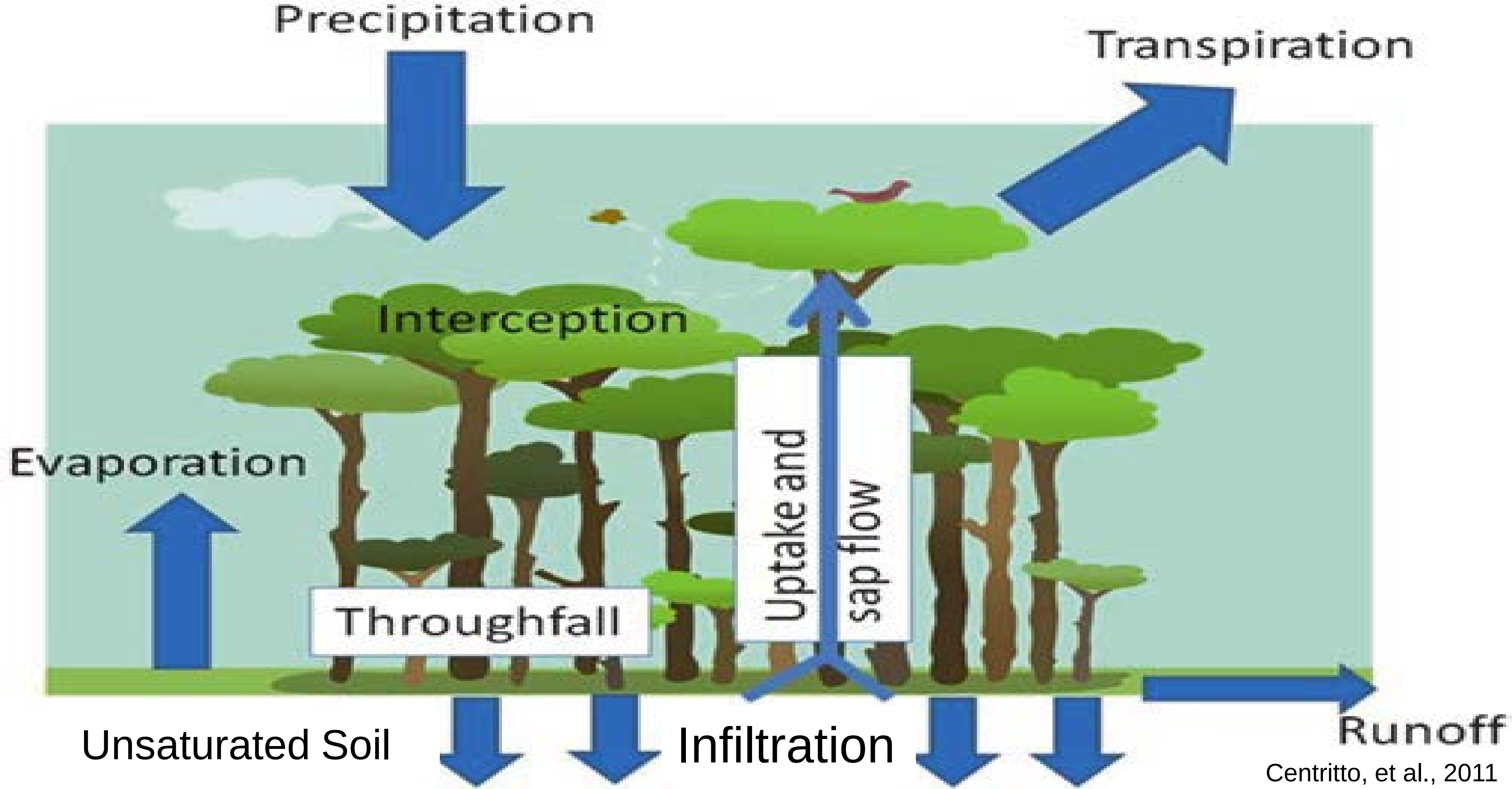
$$\sigma = F/A.$$

A =gross cross-sectional area of representative element.

The **net total stress ($\sigma - u_a$)** is the total stress minus the pore air pressure.

External Forces

The soil matric suction, s: Matric suction is associated with the soil moisture state and is applied/controlled external to the soil, e.g. by climate, irrigation, or plants



Centritto, et al., 2011

So, What is Soil Suction?

Total suction is the energy required for extracting unit volume of water from soil. It is comprised of two parts: osmotic (due to salts in pore water) and matric.

- Total suction can be determined by measurement of vapor pressure in equilibrium with the water in the soil, i.e., essentially a Relative Humidity measurement

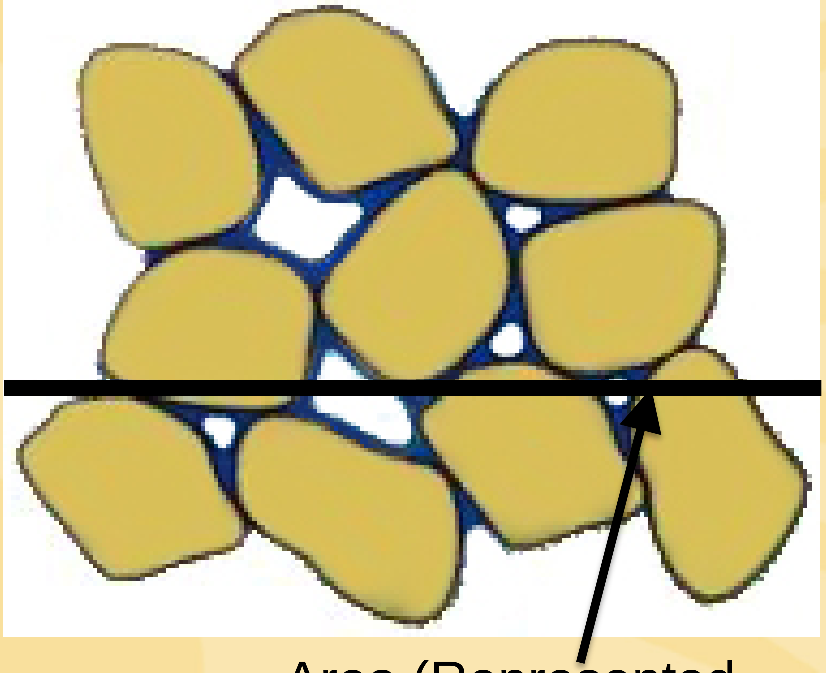
Matric suction is simply the part of total suction that is not osmotic (Krahn and Fredlund, 1971; Klute, 1986).

- Matric suction is associated with a representative element of soil containing many grains/particles of soil
- Matric suction is associated with the gross cross-sectional area of a representative element.

State of Stress of Soils

What is the Gross Cross-Sectional Area?

- In the discipline of soil mechanics, it is the gross cross-sectional area that is used in defining stress.
- This means the Area represents an unbiased plane that cuts across solid soil particles, the voids between them, and anything in the voids.



Area (Represented as a Plane)

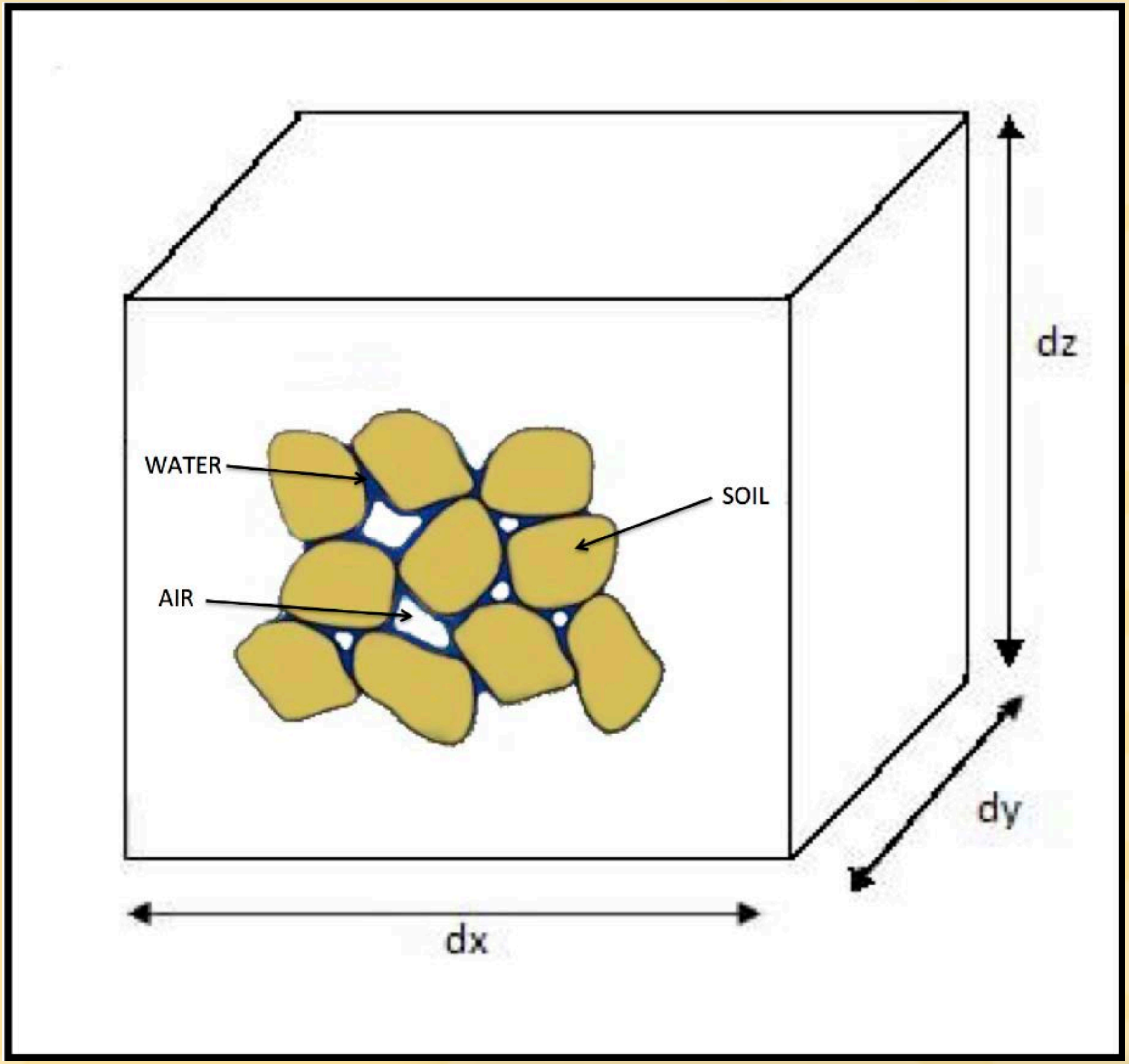
Why Use Gross Cross-Sectional Area in Defining Stress?

- Referencing to the soil gross cross-sectional area is also equivalent to treating soil as continuous media.

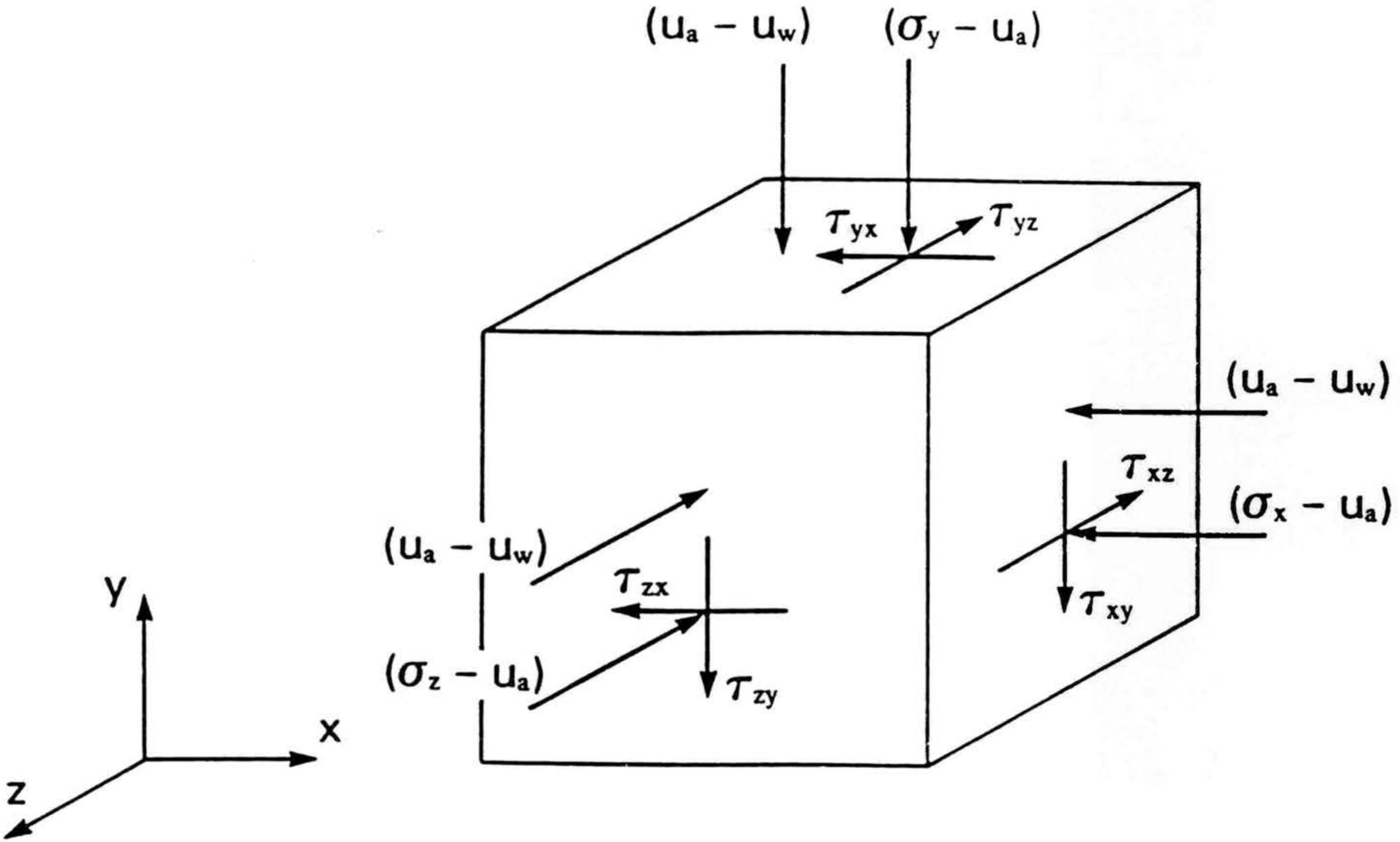
- Sometimes this is referred to as taking a **macro-level** approach.

The soil element is conceptually larger than the soil particle and void space size.

As shown, the cubical element contains a representative number of soil particles, air, and water.



Stresses on Representative Soil Element – Stresses Applied External to the Element



Simplifications for Saturated Soil Conditions

- As a soil becomes wetter, more of the void space is filled with water and less is filled with air. The matric suction decreases with increasing water content.
- As water is added to an unsaturated soil and the soil becomes very wet, the pore air becomes discontinuous—it exists as bubbles.

Simplifications for Saturated Soil Conditions

- As the air space in the voids approaches zero, the air pressure, u_a, becomes ineffective in controlling behavior.
- Soil becomes a two phase medium as degree of saturation approaches 100%.
- Thus, for saturated soils, there are only two remaining stresses: σ and u_w.

Simplifications for Saturated Soil Conditions

When pore water pressure is **negative** it tends to pull soil grains/particles together. However, when pore water pressure is **positive**, the water pressure tends to push the soil grains apart.

- Pore water pressure is **negative** for saturated soils **above the groundwater table**.
- Pore water pressure is **positive** for saturated soils **below the groundwater table**.

Simplifications for Saturated Soil Conditions

For saturated soil conditions, it is possible to combine the total stress and pore water pressure into one "net" stress that is effective in controlling the deformation response and shear strength of saturated soils. This net stress is called the Effective Stress, σ' (Terzaghi, 1936).

Effective Stress for Saturated Soil

$$\sigma' = \sigma - u_w$$

SUMMARY - Stress State of Soil

1. The stress state of a soil is, for the general case, determined by two separate stress state variables:

$\sigma - u_a$ **Net Total Stress**

and

s **Matric Soil Suction**

2. **For the special case of saturated soil**, the above stress state is consistent with Terzaghi (1936) who found that the shear strength and volume change of a saturated soil was controlled by one single net stress, termed the "effective" stress:

$$\sigma' = \sigma - u_w$$

The Role of

GEOTECHNICAL RESEARCHERS

in the STUDY of

UNSATURATED SOILS

WHAT RESEARCHERS SHOULD DO IS SUBSTANTIAL

1. DEVELOPMENT OF UNSATURATED SOIL MECHANICS THEORY
    - Theory is the Glue that Holds the Fundamental Concepts of Soil Behavior Together Across All of the Countries of the World

2. ESTABLISHMENT OF TESTING METHODS THAT ALLOW FOR MEASUREMENT/CONTROL OF STRESS STATE IN LAB AND FIELD.

3. DEVELOPMENT OF CONSTITUTIVE MODELS

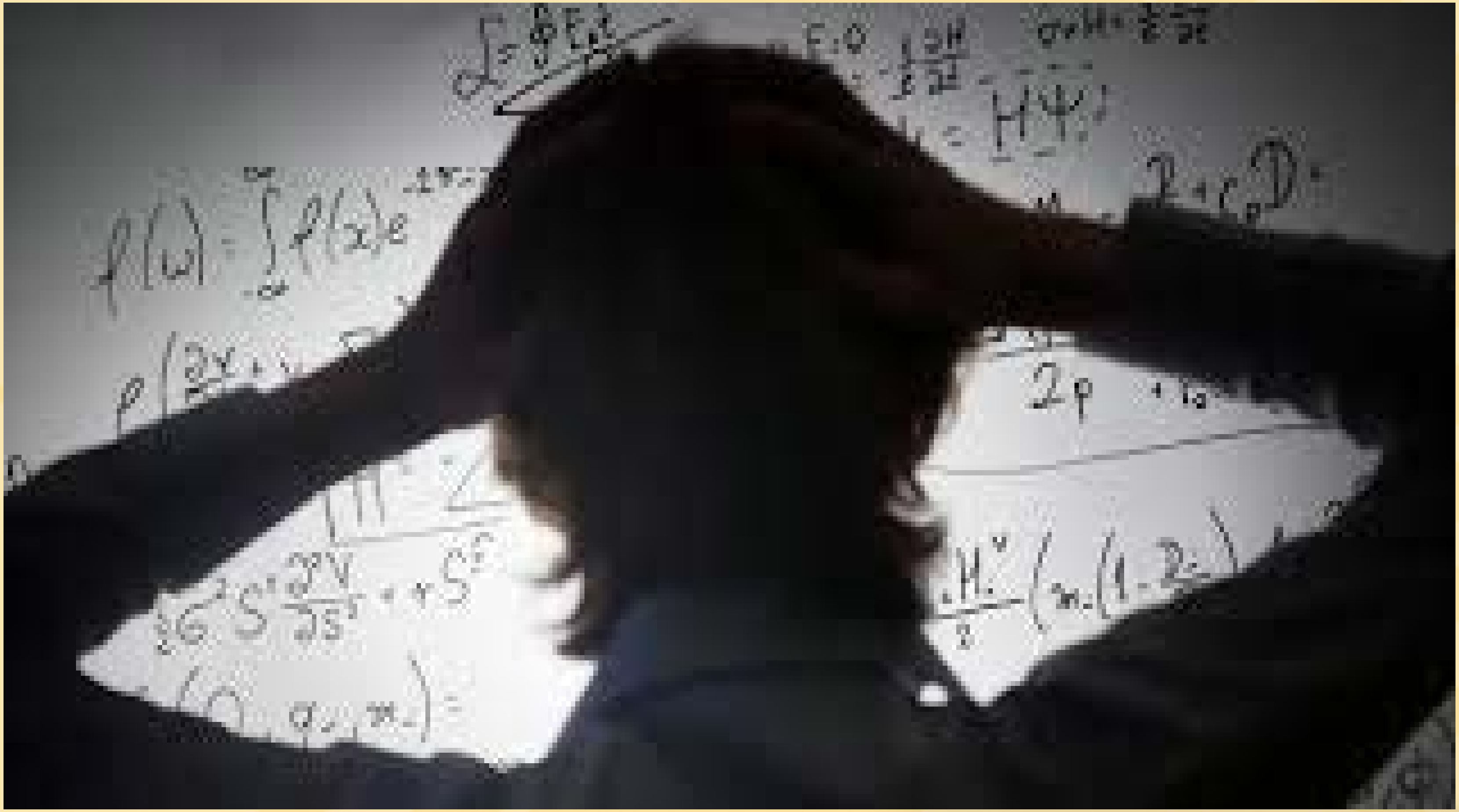
WHAT RESEARCHERS SHOULD DO IS SUBSTANTIAL

4. ESTABLISHMENT OF APPROACHES FOR SITE INVESTIGATION, PROPERTY DETERMINATION, AND DESIGN PARAMETERS THAT CAN BE PRACTICALLY USED BY GEOTECHNICAL PROFESSIONALS

5. DEMONSTRATION OF THEORY/METHODS

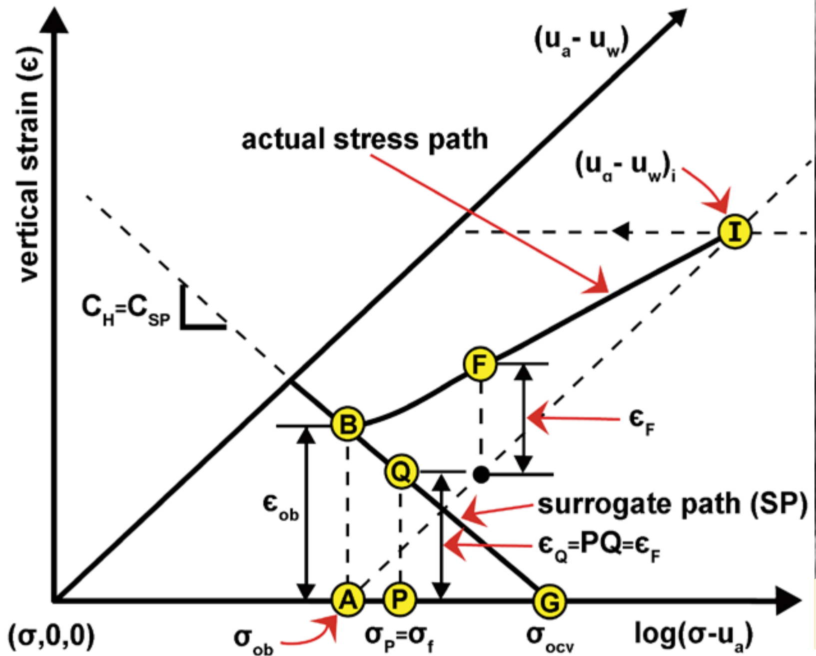
6. SEARCH FOR CONTINUOUS IMPROVEMENTS, “BREAK THROUGHS” AND ENHANCED UNDERSTANDING

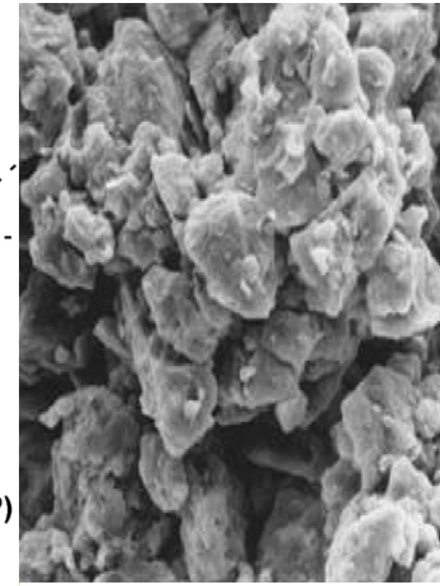
Research Papers and Conferences on Unsaturated Soils

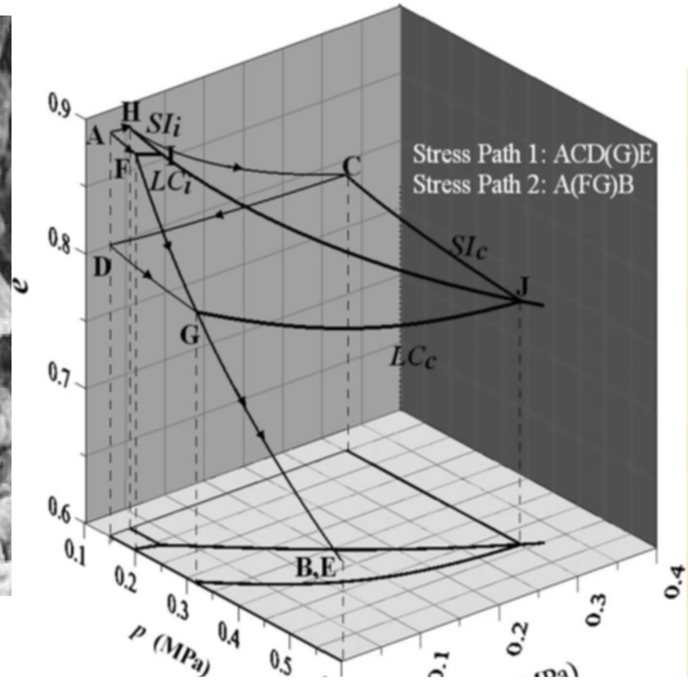


phys.org (Shutterstock)

3-D plots, PDE's, SEM photos, Finite Element Analyses, Loading Collapse Curve, Coupled Processes,





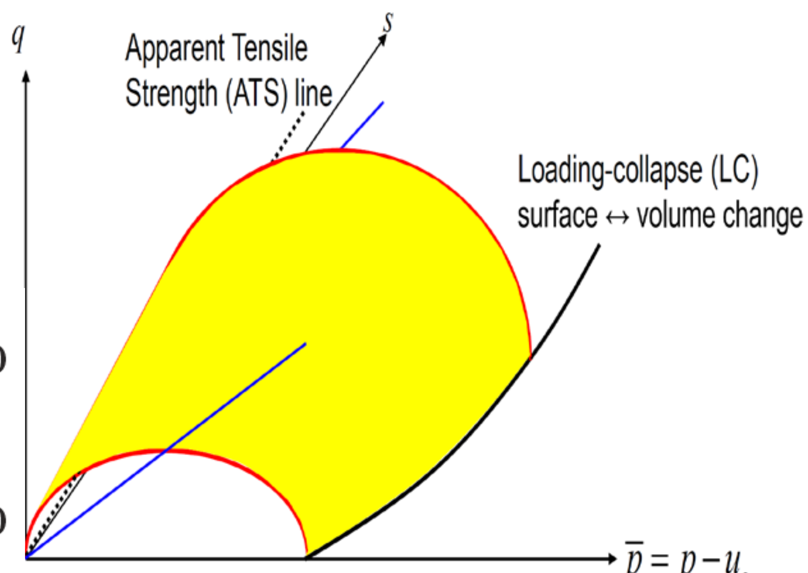


$$\frac{\partial}{\partial x}\left[\left(k_x^w(\theta)+k^{vd}(\theta)\right)\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[\left(k_y^w(\theta)+k^{vd}(\theta)\right)\frac{\partial h}{\partial y}-k^{vd}(\theta)\right]=\frac{\partial \theta}{\partial t}$$

$$c_{33}\frac{\partial}{\partial x}\left(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(c_{12}\frac{\partial u}{\partial x}+c_{22}\frac{\partial v}{\partial y}\right)-d_s\frac{\partial(u_a-u_w)}{\partial y}+b_y=0$$

$$\frac{\partial(\sigma_x-u_w)}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}+\frac{n_s\,\partial u_w}{\partial x}+n_s\rho_s g+F_{sx}^w=0$$

$$\frac{\partial \tau_{xu}}{\partial x}+\frac{\partial(\sigma_y-u_w)}{\partial y}+\frac{\partial \tau_{zy}}{\partial z}+\frac{n_s\,\partial u_w}{\partial y}+n_s\rho_s g+F_{sy}^w=0$$



Unsaturated Soils Conference Attendees

Single-Valued "Effective Stress" Equations for Unsaturated Soils: Discarded in late 1960's/1970's.

- **Bishop's Effective Stress Equation (1955, 1959)**

$$\sigma' = (\sigma - u_a) + \chi(u_a - u_w)$$

- **Croney et al., Effective Stress Equation (1958)**

$$\sigma' = (\sigma - \beta' u_w)$$

- **Jenning's Effective Stress Equation (1961)**

$$\sigma' = (\sigma + \beta\ p'')$$

- **Aitchison's Effective Stress Equation (1961, later changed)**

$$\sigma' = (\sigma + \psi p'')$$

- **Richard's Effective Stress Equation (1966)**

$$\sigma' = (\sigma - u_a) + \chi_m(h_m + u_a) + \chi_s(h_s + u_a)$$

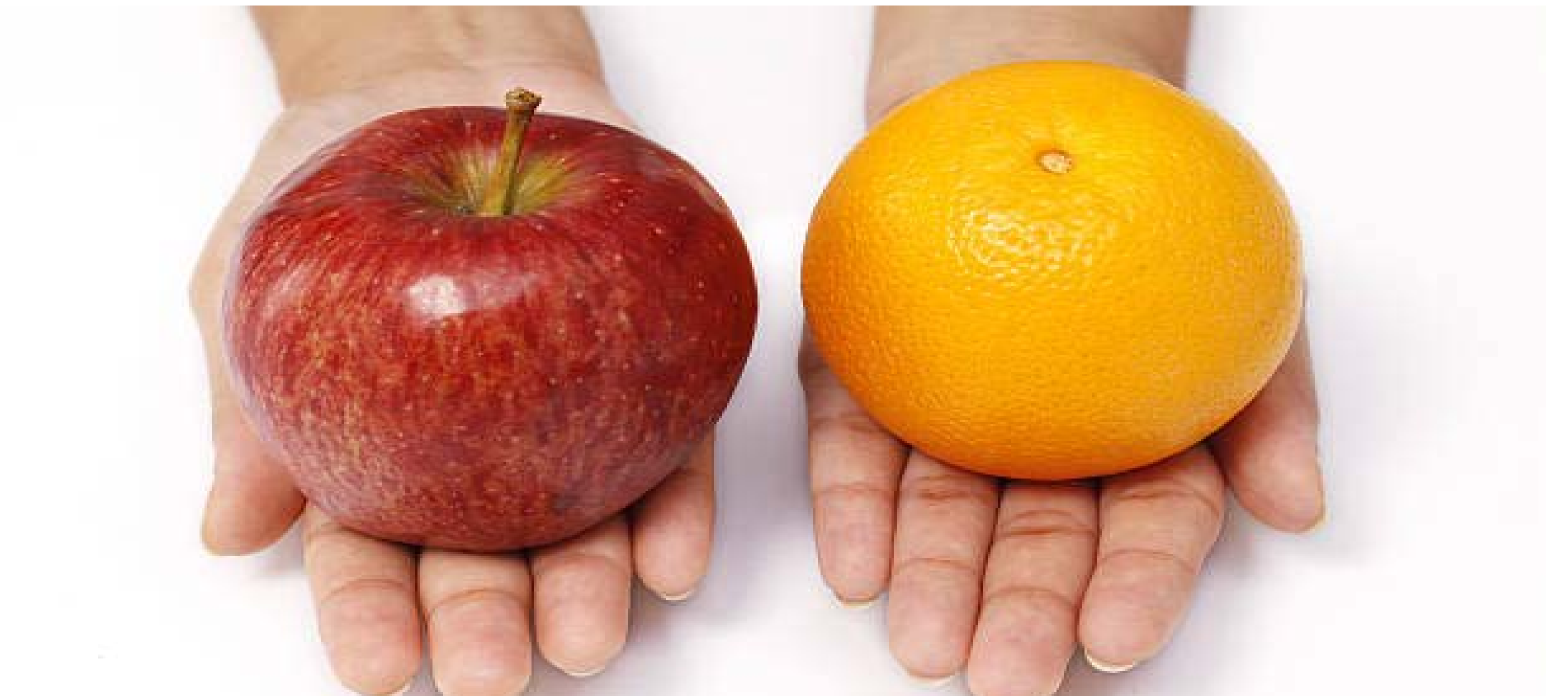
IN SPITE OF A SOUND FRAMEWORK IN TERMS OF TWO MEASURABLE STRESS VARAIABLES AS OF THE 1970's, AND HAVING ABANDONED THE SEARCH FOR SINGLE-VALUED EFFECTIVE STRESS AS OF THE 1960's, THE SEARCH FOR A SINGLE "EFFECTIVE STRESS" STARTED AGAIN AROUND THE EARLY 2000'S:

Khalili and Khabaz (1998); Khalili, Geiser, Blight (2005); Wheeler, Sharma, Buisson (2003); Gallipoli, Gens, Sharma, Vaunat (2003); Tamagnini (2004); Lu and Griffiths (2004);Lu and Likos (2006), Lu, Godt, and Wu (2010)…

WHY DOES THE SEARCH FOR A SINGLE-VALUED EFFECTIVE STRESS FOR UNSATURATED SOILS NEED TO STOP?

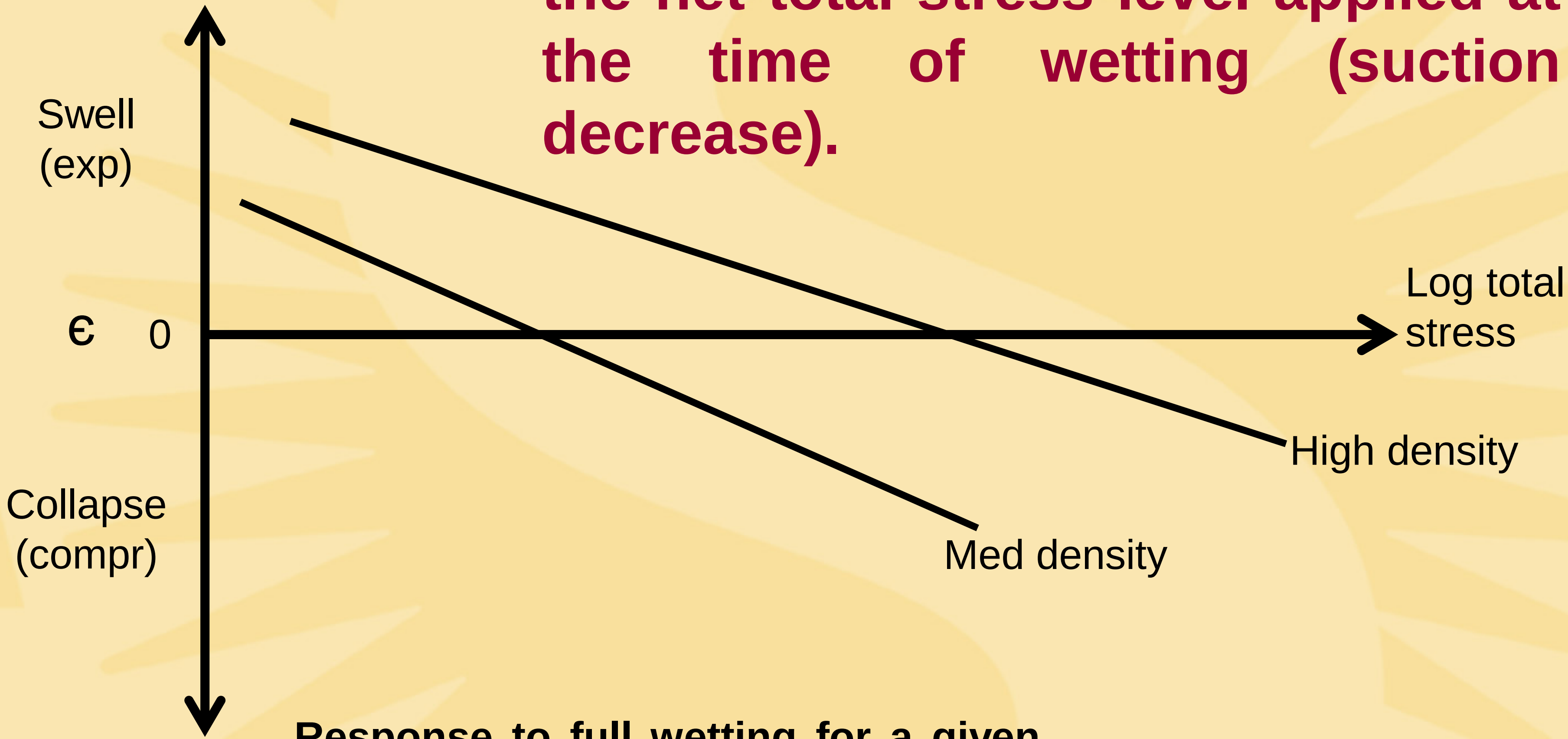
$$\sigma' = (\sigma - u_a) + \chi(u_a - u_w)$$

Bishop's effective stress equation "proved to have little impact on practice." (Morgenstern, 1979)



Net Total Stress, $(\sigma - u_a)$ Matric Suction, s

-Any cohesive soil can expand or collapse (compress) depending on the net total stress level applied at the time of wetting (suction decrease).

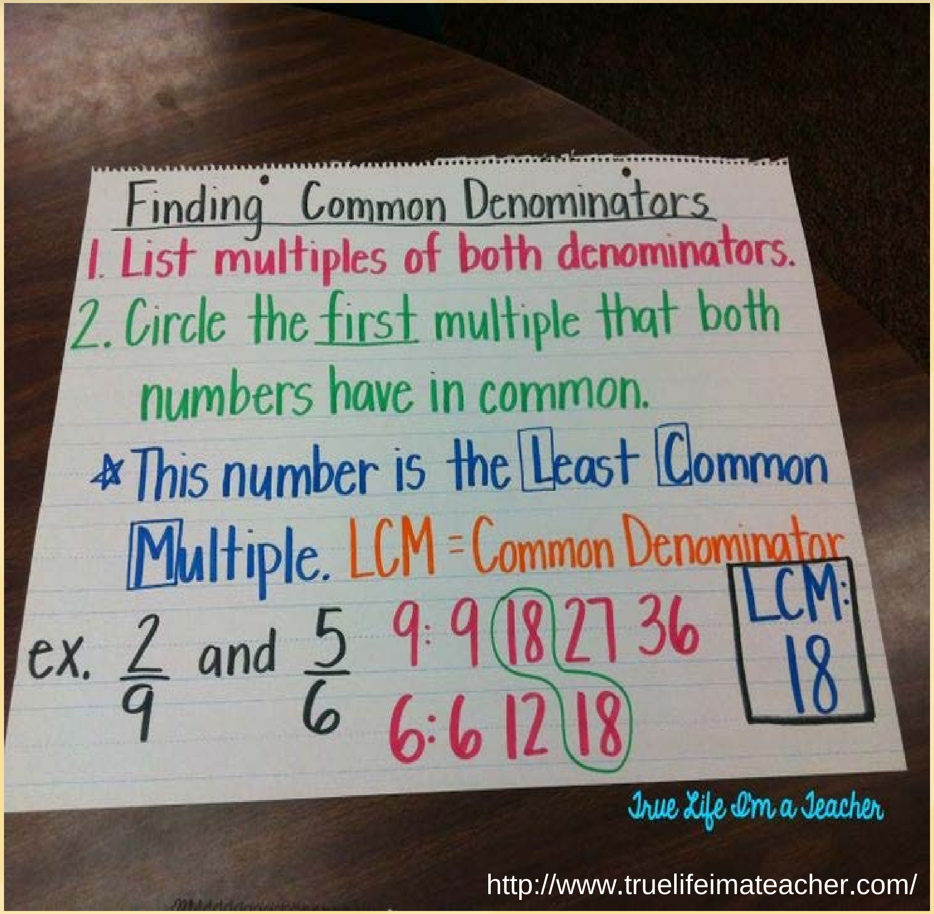


Response to full wetting for a given clayey soil at a given initial moisture content (suction)

-The effect of increase in net stress depends on the matric suction level at the time of loading.

Image via Wikipedia - http://en.wikipedia.org/wiki/File:Sand_sculpture.jpg

- An increase in suction (drying of soil) typically increases shear strength, but if "high enough" can reduce shear strength of granular soils.



There is no "common denominator" that can be used to combine effects of (σ - u_a) and s such that a single-valued stress-state formulation combination is appropriate for description of both shear strength and volume change behavior of unsaturated soils – known since 1960's,

And

It was Confirmed at the 1st International Conference on Unsaturated Soils, 1995 (Gens, 1996; Wheeler and Karube, 1996).

PROBLEMS WITH THE MANNER OF RE-INTRODUCTION OF THE SINGLE-VALUED EFECTIVE STRESS:

- **Bishop's "effective stress" for unsaturated soils is not controllable in the laboratory, nor is the suction stress (a form of single-valued effective stress introduced by Lu and Likos, 2006) – not commonly acknowledged.**

- **Net total stress and suction controlled tests are required to determine any single-valued "effective stress".**

A Single-Valued Effective Stress for Unsaturated Soils Requires the Performance of Suction-Controlled Laboratory Tests Before the "Effective Stress State" Can be Known.

COMPARE TO ROUTINE PRACTICE STRESS COMPS

- Effective stress for saturated soils is computed as (σ-u_w) – a simple computation with no laboratory testing required.

- Stress in concrete is computed as applied load divided by the gross cross-sectional area (σ = P/A) - a simple computation with no lab tests needed to get the modulus of the concrete as a prerequisite to the stress computation.

ROUTINE PRACTICE STRESS COMPS REQUIRE MATERIAL PROPERTIES

An Equation is "Constitutive" when it incorporates Material Properties along with Variables of "State" such as Stress, Strain, Volume, or Temperature.

A Constitutive Equation Relates, for example, Stress to Strain through a material property:

- **Hooke's law, which incorporates a material property, E**
- **e-log p curves which incorporate a soil property, C_c.**

State of Stress, at the macro-level, is not constitutive in nature

- **$\sigma = P/A$ is not a constitutive equation and it involves no material properties**

Any Single-Valued "Effective Stress" for Unsaturated Soils is constitutive in nature - soil-type dependent, stress path/history dependent, and requiring laboratory testing as a prerequisite to stress state computation.

Unsaturated Soils Researchers have not consistently and clearly articulated the problems with single-valued effective stress constitutive equations for unsaturated soils.

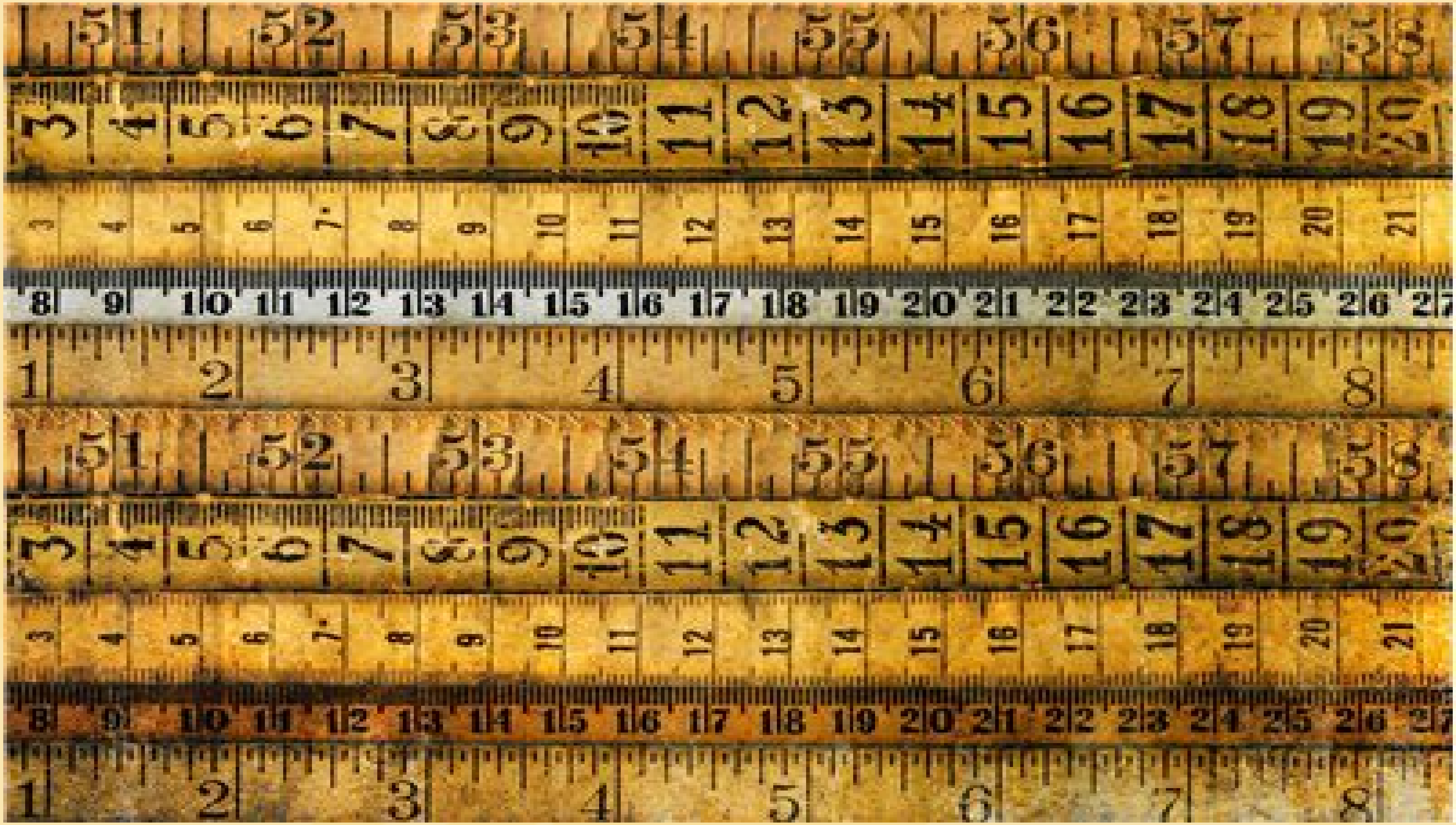
So What Does this Have to do with Implementation of Unsat into Practice?

As a group, unsaturated soils researchers have left the erroneous overall impression that the framework for unsaturated soil mechanics is still unresolved, even at a level so basic as the stress state.

Of course, this impression impedes implementation into routine practice.

This impression is completely wrong. We can and have solved real world problems using the two stress variables of net total stress and matric suction.

A Different Measuring Stick for Unsaturated Soils



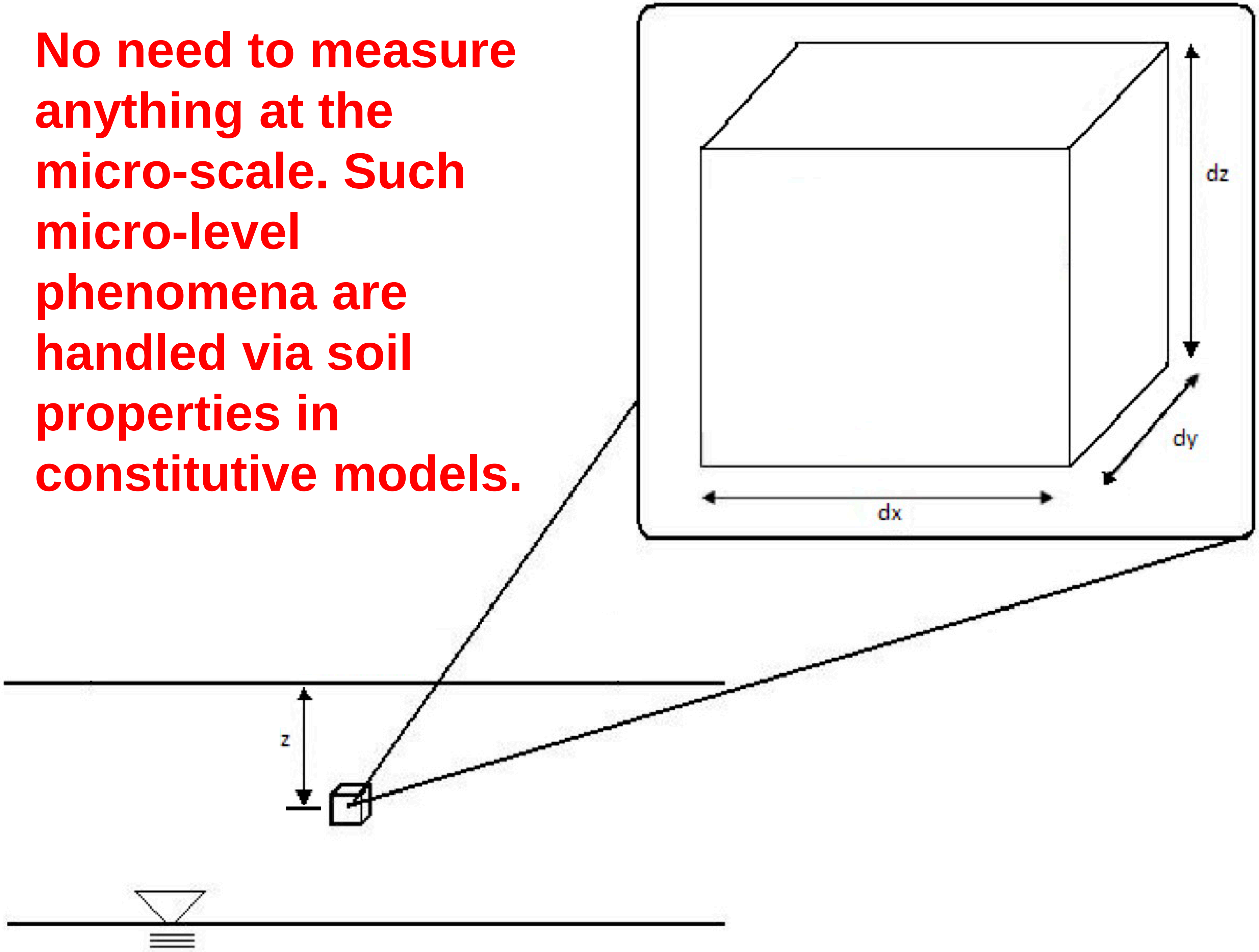
http://www.historyofpencils.com/images/historyofpencils/ruler-measure-small.jpg

Terzaghi, Peck, and Mesri (1996) – on Effective Stress for Saturated Soil

It is evident that the mechanism of the transfer of effective stress from one particle to another is complex. Fortunately, although no theoretical basis for Eq. 15.2 has been found, its empirical basis is so well established that a quantitative knowledge of the interparticle reactions is not needed.

IN OTHER WORDS, TERZAGHI VISUALIZED GEOTECHNICAL ENGINEERING IN THE CONTEXT OF CONTINUUM MECHANICS – A RELATIVELY NEW AND EMERGING FIELD AT THE TIME TERZAGHI PROPOSED THE EFFECTIVE STRESS EQUATION FOR SATURATED SOILS.

No need to measure anything at the micro-scale. Such micro-level phenomena are handled via soil properties in constitutive models.



It is not necessary to separate out the micro level phenomena – although study at the micro level can certainly have illuminating impacts on understanding unsaturated soil behavior, much like the work of Mitchell and Lamb had on saturated soil behavior.

While micro-to-macro models do have a place in research, there are few, if any, practice applications where such models are required.

Micro-to-macro models also exist for saturated soils and are appropriate for special cases – and/or research. However, such models do not dominate the PRACTICE of geotechnical engineering and are not likely to do so. For that matter, neither do some of the more complex elasto-plastic constitutive models requiring numerous soil parameters and FEM.

If it's ok in saturated soil mechanics, why not in unsat?

A DIFFERENT MEASURING STICK

- A Macro Approach is Well Established and Routinely Used with Saturated Soils Mechanics

- A Review of Unsat Research Literature Can Leave the Impression that a Micro Approach is Important, if Not Critical, to Application of Unsaturated Soils Theory.

However, There is Essentially No Difference Between the Two, as a Saturated Soil also has a Micro Component, and Yet it is ‘By and Large’ Not Considered in Routine Application.

A MACRO APPROACH SHOULD BE VIEWED AS APPROPRIATE FOR UNSATURATED SOIL AS WELL, THEREBY NOT HOLDING UP THE “SHOW” ON IMPLEMENTATION

THE ROLE OF

PRACTITIONERS

COMMON APPROACH TO UNSATURATED SOILS IN GEOTECHNICAL PRACTICE

– POTENTIALLY UNCONSERVATIVE DESIGNS AND PROCEDURES THAT LEAD TO FAILURES OR CONSTRUCTION DIFFICULTIES (e.g. ASSUME SOIL WILL NEVER GET WETTED)

MOST COMMON

– OVER-CONSERVATISM THAT LEADS TO MUCH HIGHER THAN NECESSARY CONSTRUCTION COSTS (e.g. ASSUME SOIL WILL GET FULLY WETTED)

Find the Geotechnical Engineers and the Lawyer in the Picture Below

Fear of litigation contributes to slow implementation of research into geotech practice, and conservatism abounds.

What practitioners want are more peer-reviewed articles that can be cited in support of using unsaturated soils theory in practice. Articles – and supporting research - describing how to take advantage of soil suction in design are needed.

A Major Issue Relates to the Source of Funding for Geotechnical Research in the USA – Which Faculty Must Have to Keep Civil Engineering Programs Relevant and Supported within the University System.

- Research funding agencies are primarily focused on fundamental research – having the potential to be transformational, addresses greater issues of society such as climate change, renewable energy, …..

- Funding for APPLIED research is very limited for Geotechnical Engineering in the USA

So, How is Funding for More Practice-Relevant Research Obtained?

Is the Seeking of Funding for Applied Research a Joint Faculty and Practitioner Responsibility?

Whatever the opinions and answers may be to these two questions, there is no question that the source of research funding affects the type of research, which in turn affects implementation of unsaturated soil mechanics into practice.

ASCE has established a Grand Challenge to reduce the life cycle cost of infrastructure by 50 percent by 2025 ... Reaching this goal will require civil engineers to … embrace the challenge to innovate and to transform our practice.

ASCE GRAND CHALLENGE

Rethink What's Possible

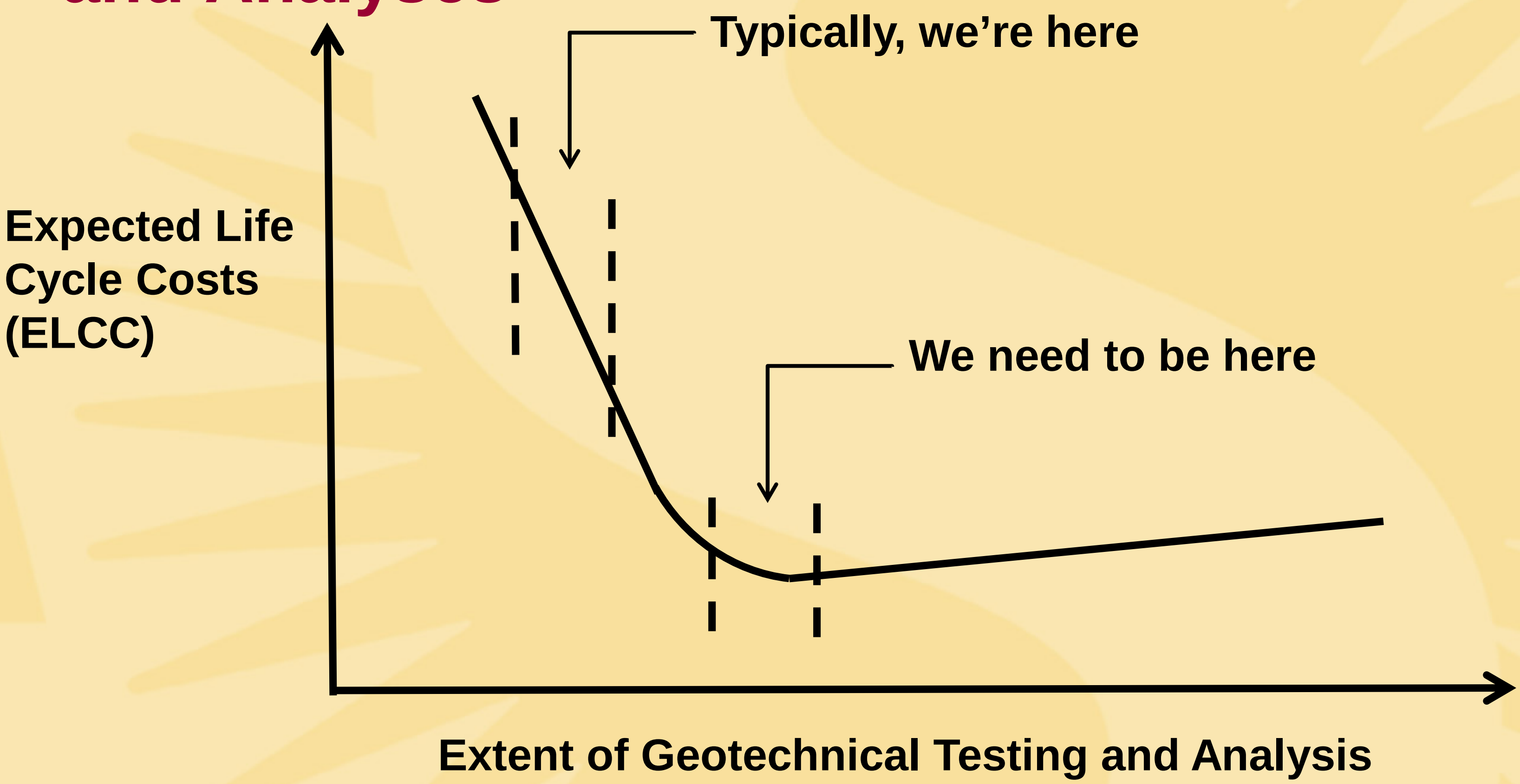
Thomas Smith III (2016)

“Movement toward prescriptive codes long precedes our current litigious bent. …I think our profession is naturally conservative because [our concern is] life safety…. So we are very conservative and I think we’ve stepped away from responsibilities that civil engineers used to have. ….”

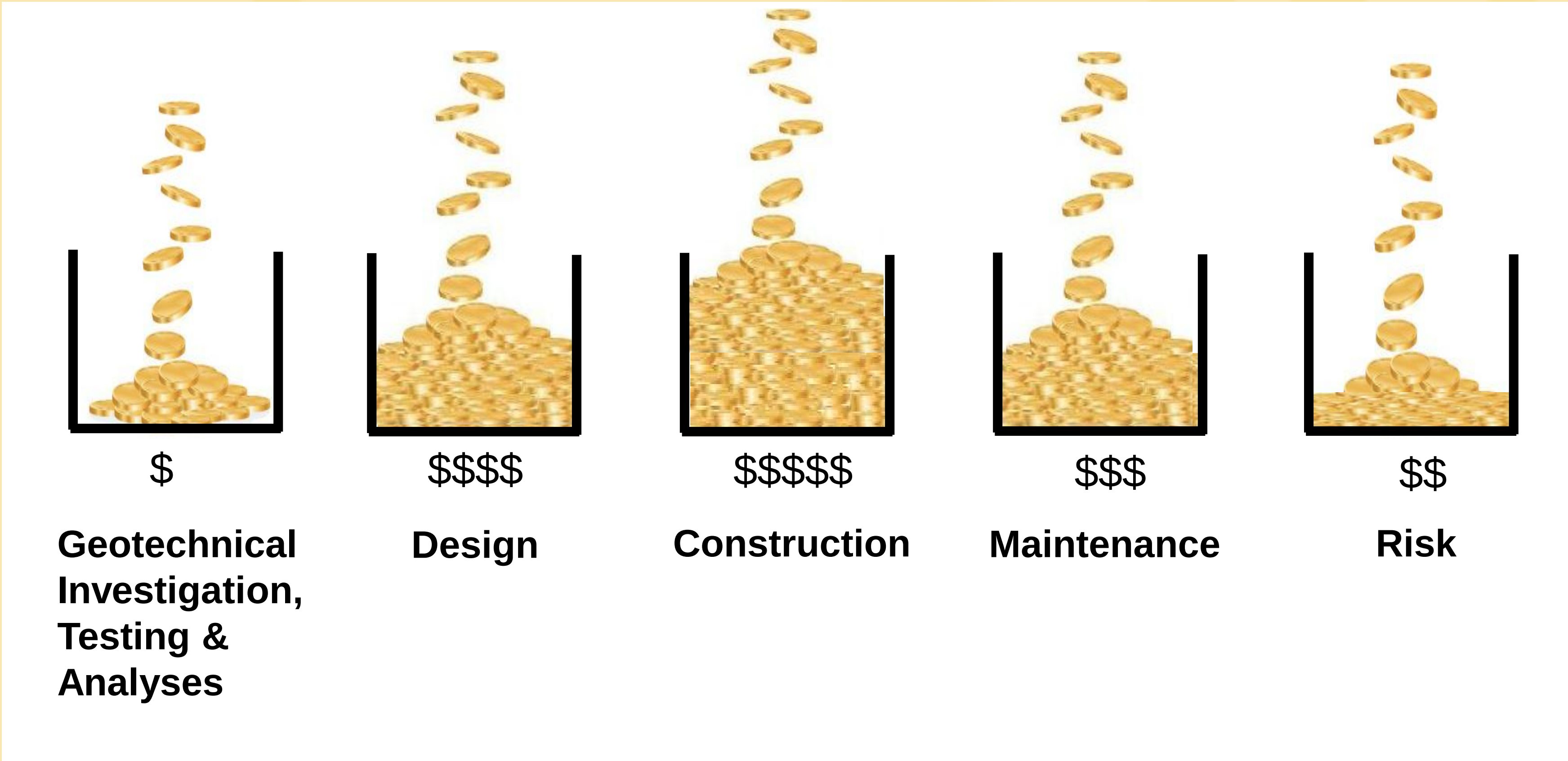
(Dusenberry, Dec. 2017 ASCE Magazine article on meeting ASCE’s Grand Challenge)

For Geotechnical Engineering, in Dealing with Problems of Unsaturated Soils, the Practice is Dominated by Overly-Conservative Design

Minimization of Expected Life Cycle Costs With Respect to the Extent of Geotechnical Testing and Analyses



Project Costs



- **An Intelligent Owner's goal: make ∑pots = minimum**

Implementation of
Unsaturated Soils Theory
in Routine Geotechnical Engineering Practice
is a Critical Part of Minimization of Cost
of Maintenance, Repair, and
Building our Infrastructure.

In general, soil suction increases stability of slopes, reduces soil settlement, increasing allowable bearing pressure - SAVES COSTS

So, What Should Practitioners be Doing?

-The impacts of change in soil suction should, as a minimum, be considered (thought about) for all geotechnical engineering works where soils exist above the GWT

- **Relatively simple, low cost modifications to routine geotechnical work provide useful aids.**

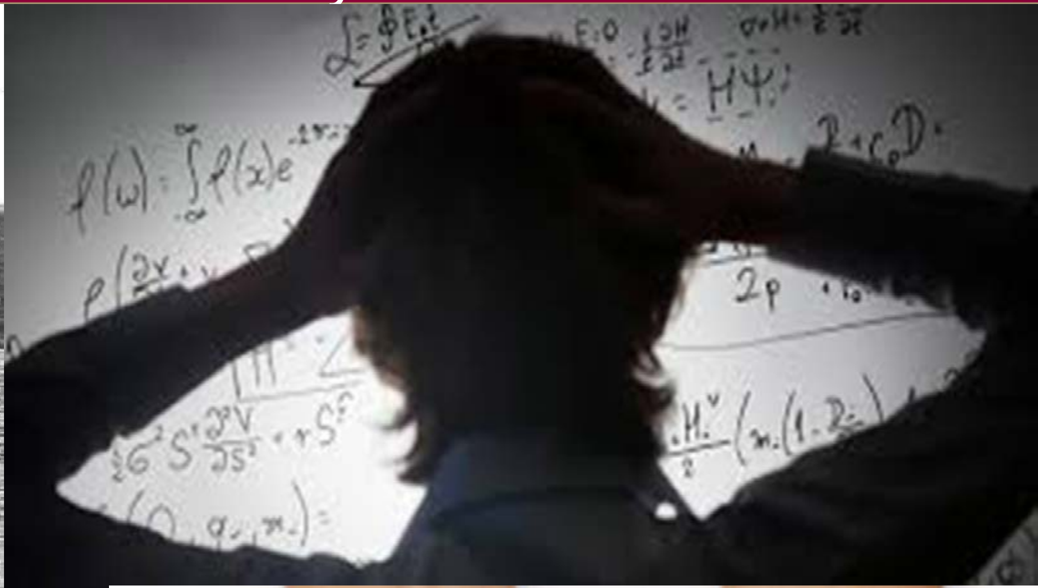
(e.g., To quantitatively evaluate if change in soil suction needs to be considered, subject soil specimens to full wetting at field total stress levels and observe the change in volume and/or shear strength compared to the field moisture state condition.)

WHY TAKE THE LEAP?

-Understanding the response of soils to changes in net total stress and suction (moisture change) leads to better and more cost-effective geotechnical engineering solutions.

-Reliance on even a very conservative estimate of soil suction that can be maintained in the field results in significant cost savings on most projects.

Lessons Learned: Unsaturated Soils Theory in Routine Practice



Lessons Learned: Unsaturated Soils Theory in Routine Practice