DESIGNING TEMPORARY SOIL NAIL WALLS USING UNSATURATED SOIL SHEAR STRENGTH

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Saturated vs. Unstaurated

- Saturated : Effective stress (σ-u_w) controls behavior
- Unsaturated : Net stress (σ-u_a) and Matric suction (u_a-u_w) control behavior
- Have seen cut slopes that are steeper than we would allow but they are stable. Why?

Their strength is not being governed by effective stress parameters (c', ϕ') but unsaturated shear strength parameters.

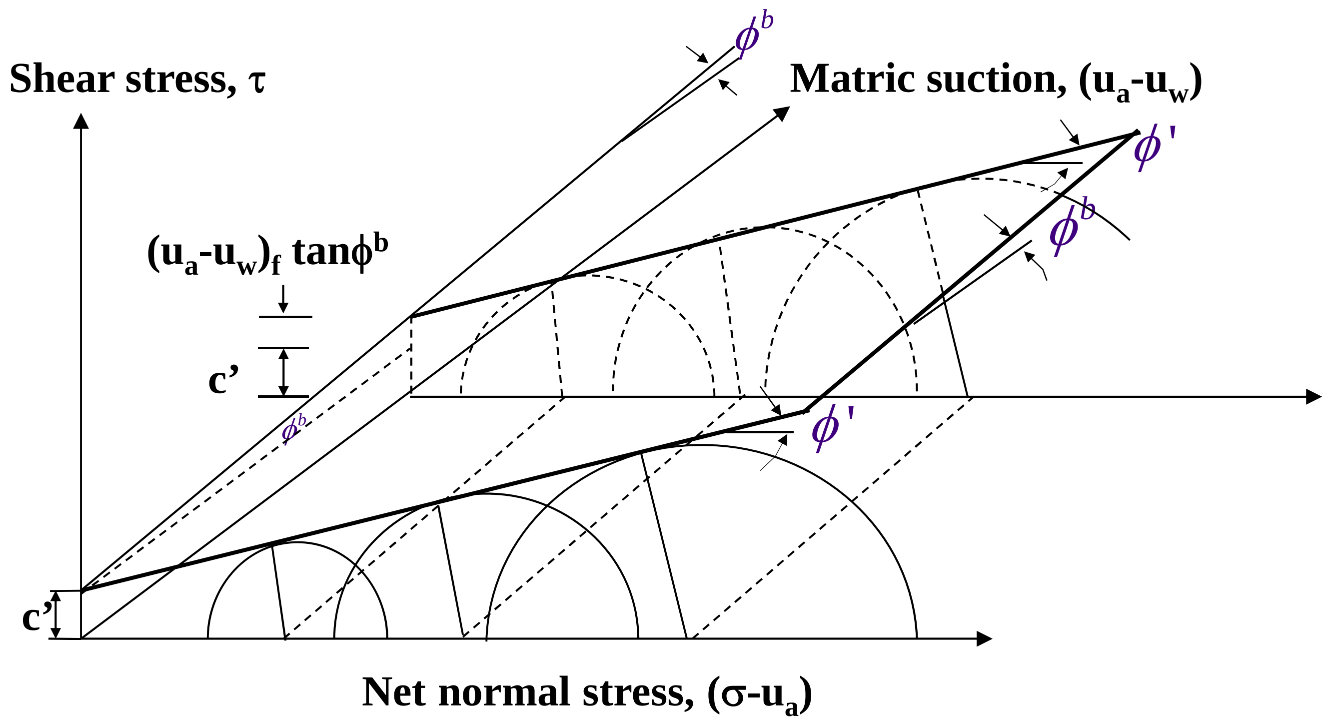
(from Anderson and Ogunro, 2008)

Unsaturated Shear Strength

- Unsaturated soil (Fredlund et al., 1978)

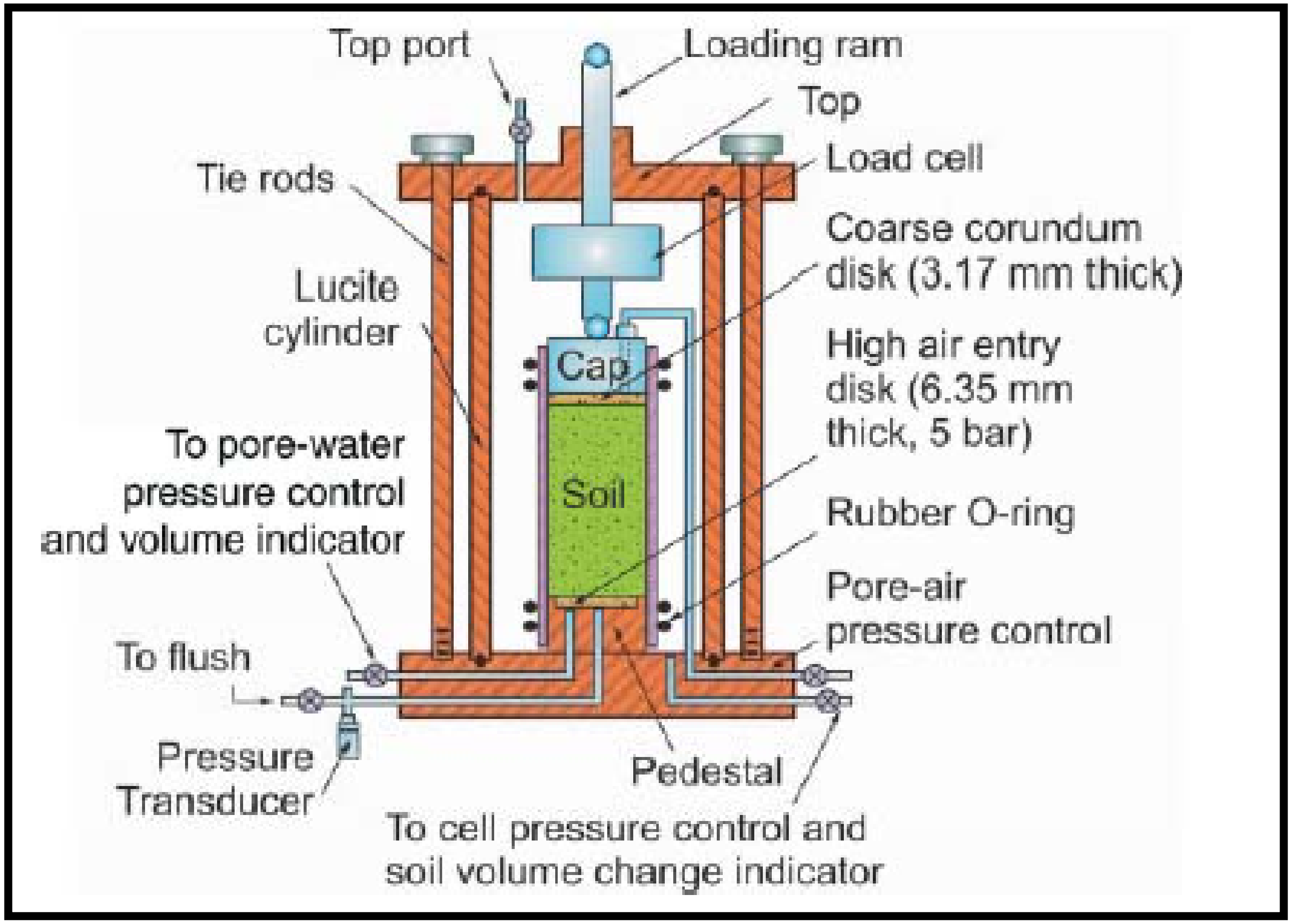
$$\tau_f = c' + (\sigma_n - u_a)_f \tan\phi' + (u_a - u_w)_f \tan\phi^b$$

Extended Mohr-Coulomb failure envelope



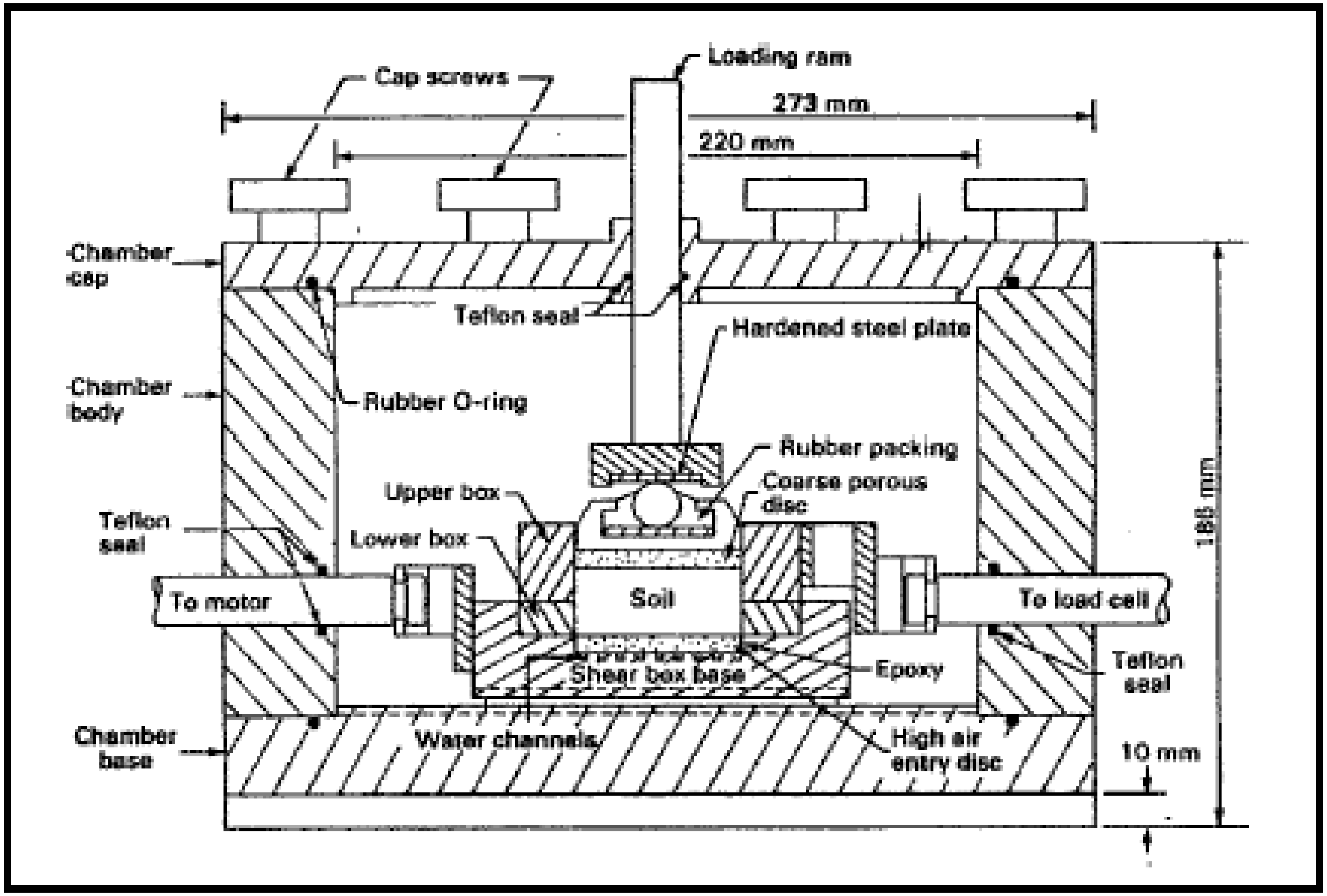
Triaxial Test

- Modified triaxial cell for testing unsaturated soils (Rahardjo et al., 2004)

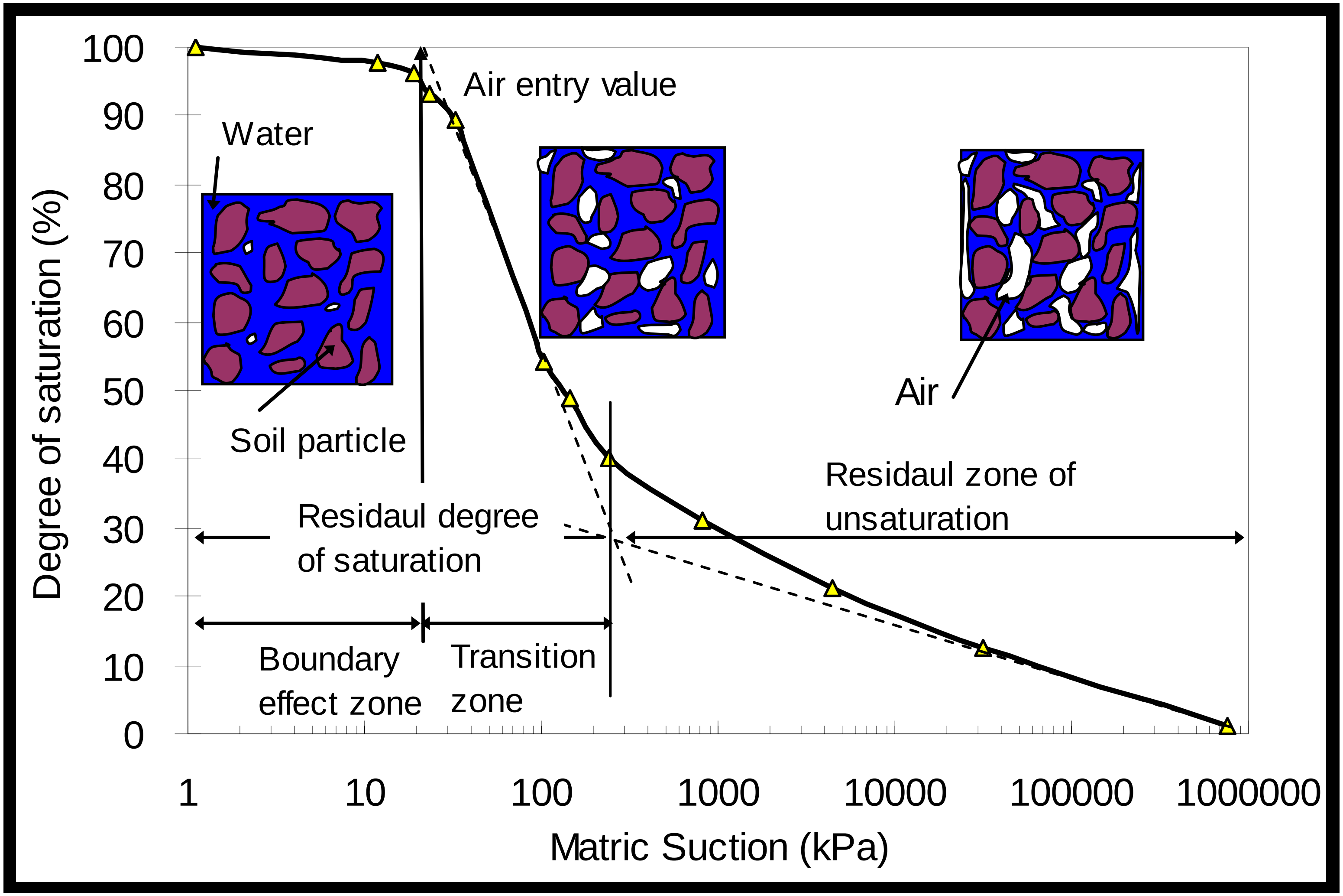


Direct Shear Test

- Modified direct shear apparatus (Gan et al., 1988)



Soil Water Characteristic Curve (SWCC)



Pressure Plate Test (ASTM 2325)

- Schematic Diagram of pressure plate extractor

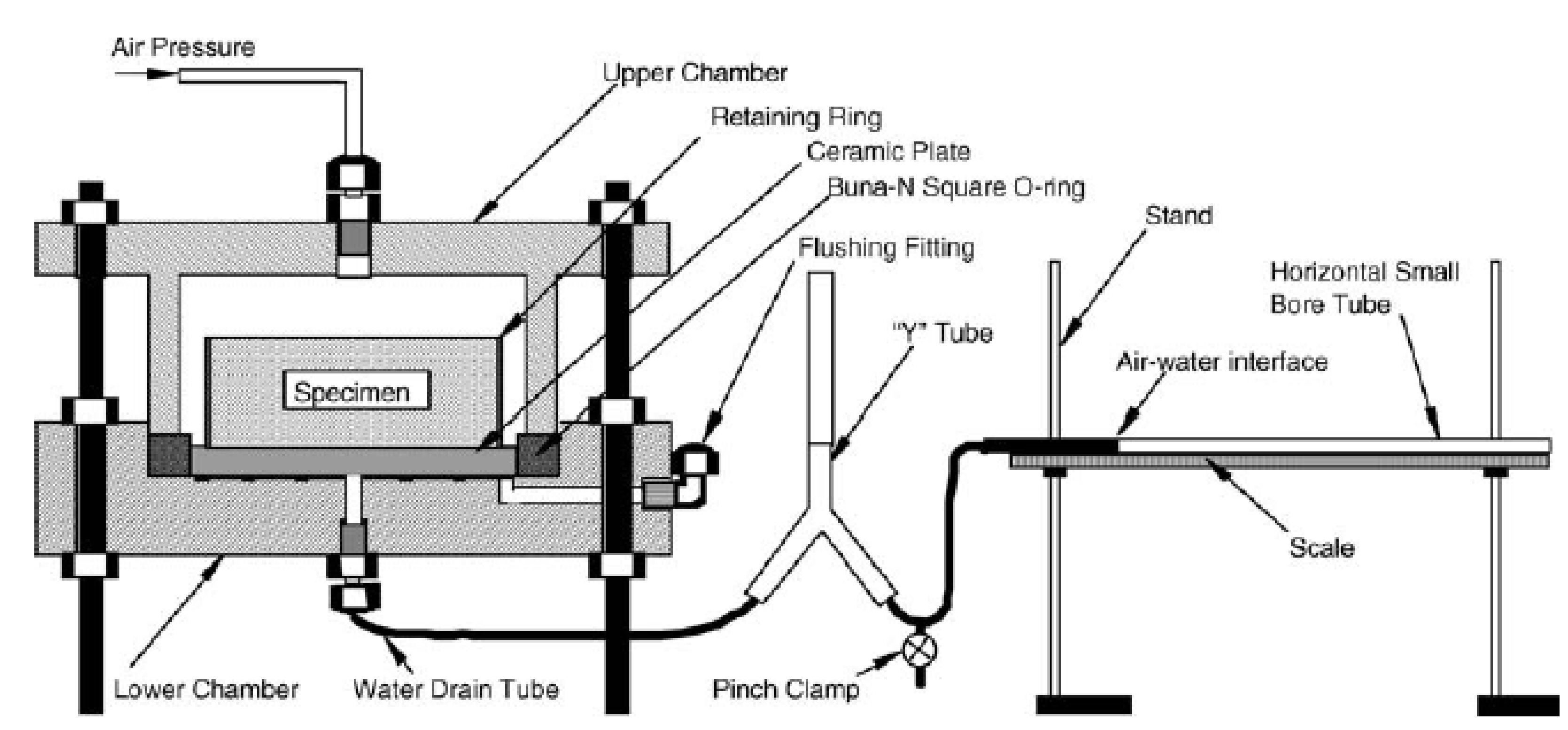
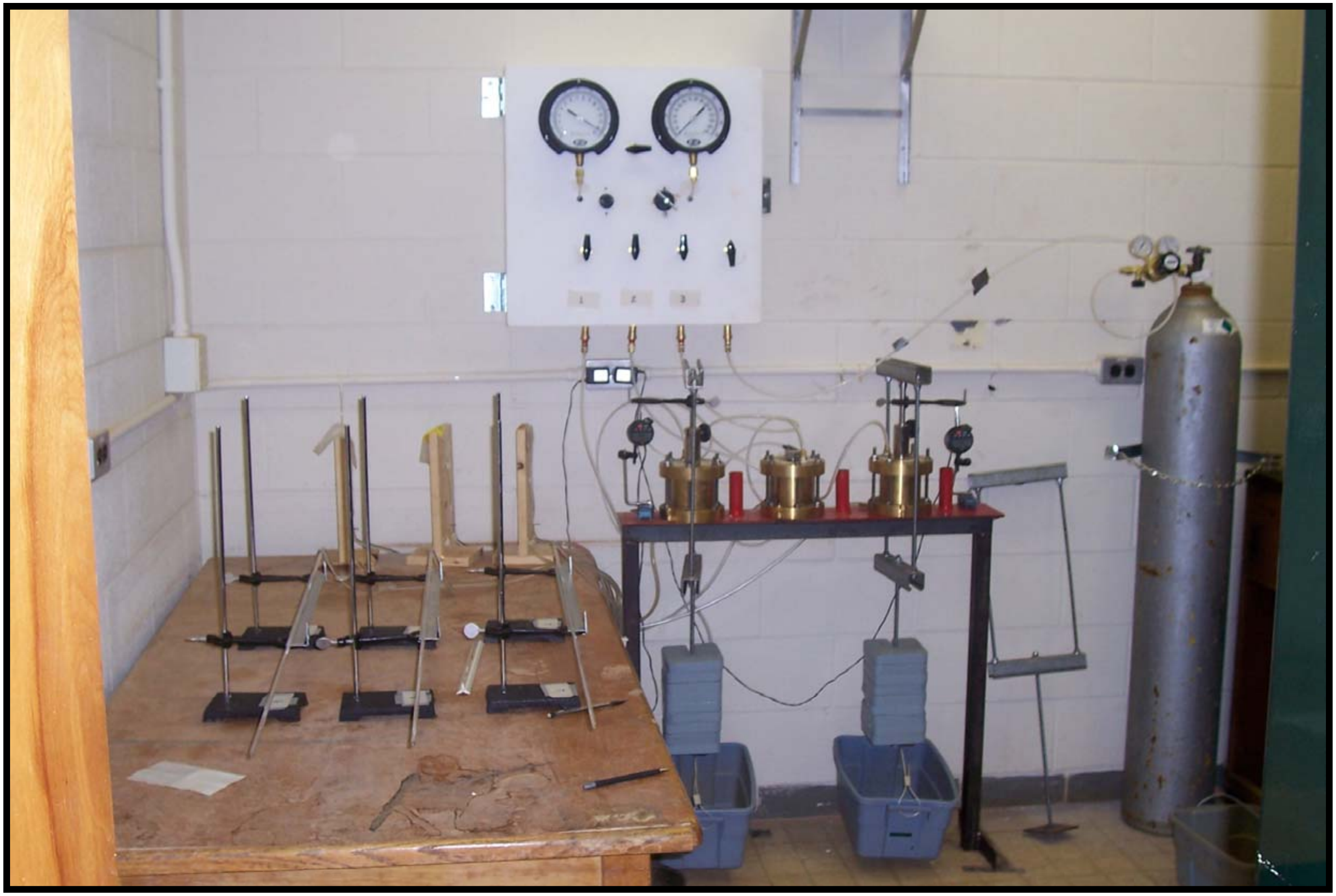


FIG. 2—*Schematic of leak-free pressure plate extractor (LFPPE).*

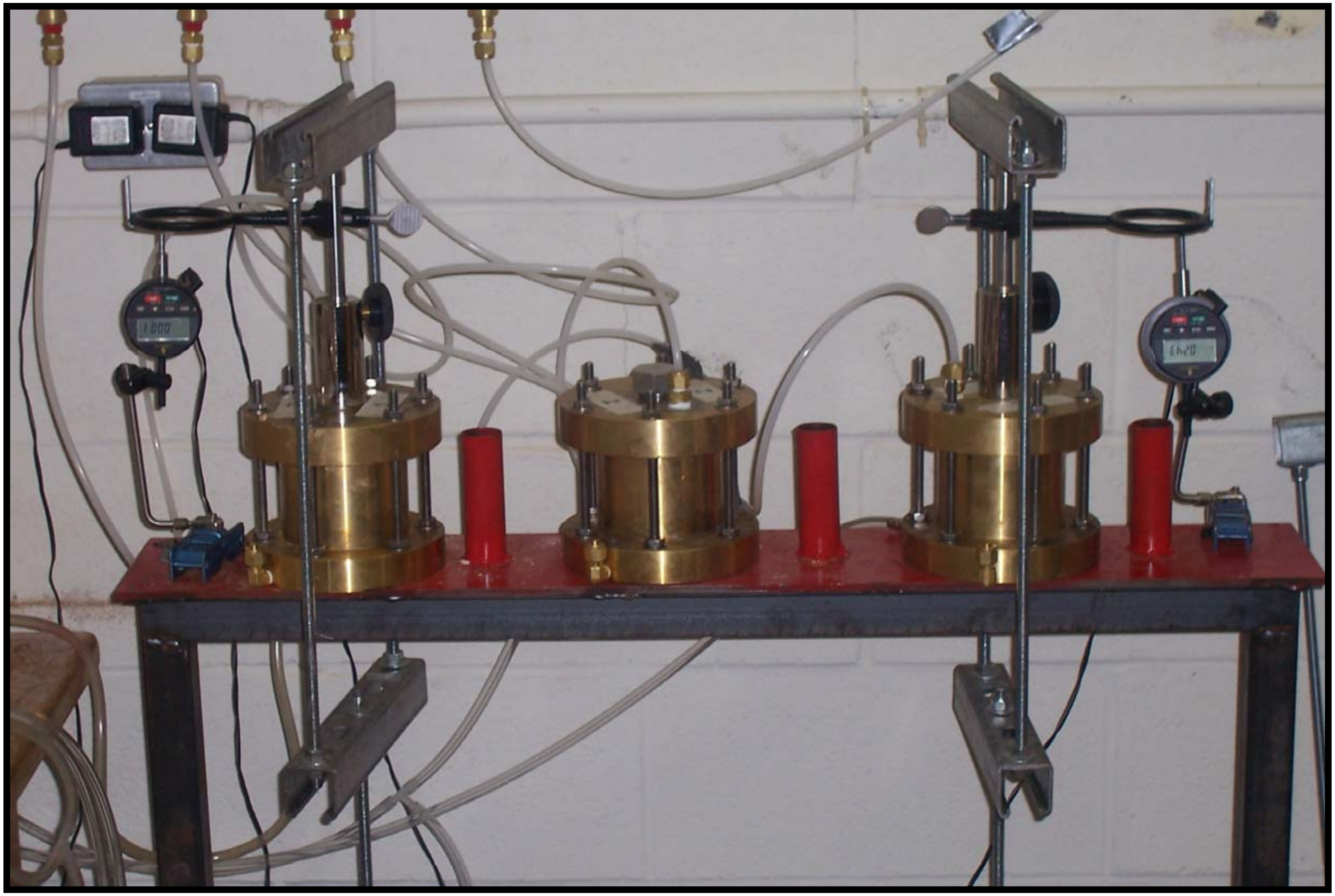
Wang and Benson (2004)

Pressure Plate Test (ASTM 2325)



(NC State University Soils Lab)

Pressure Plate Test (ASTM 2325)



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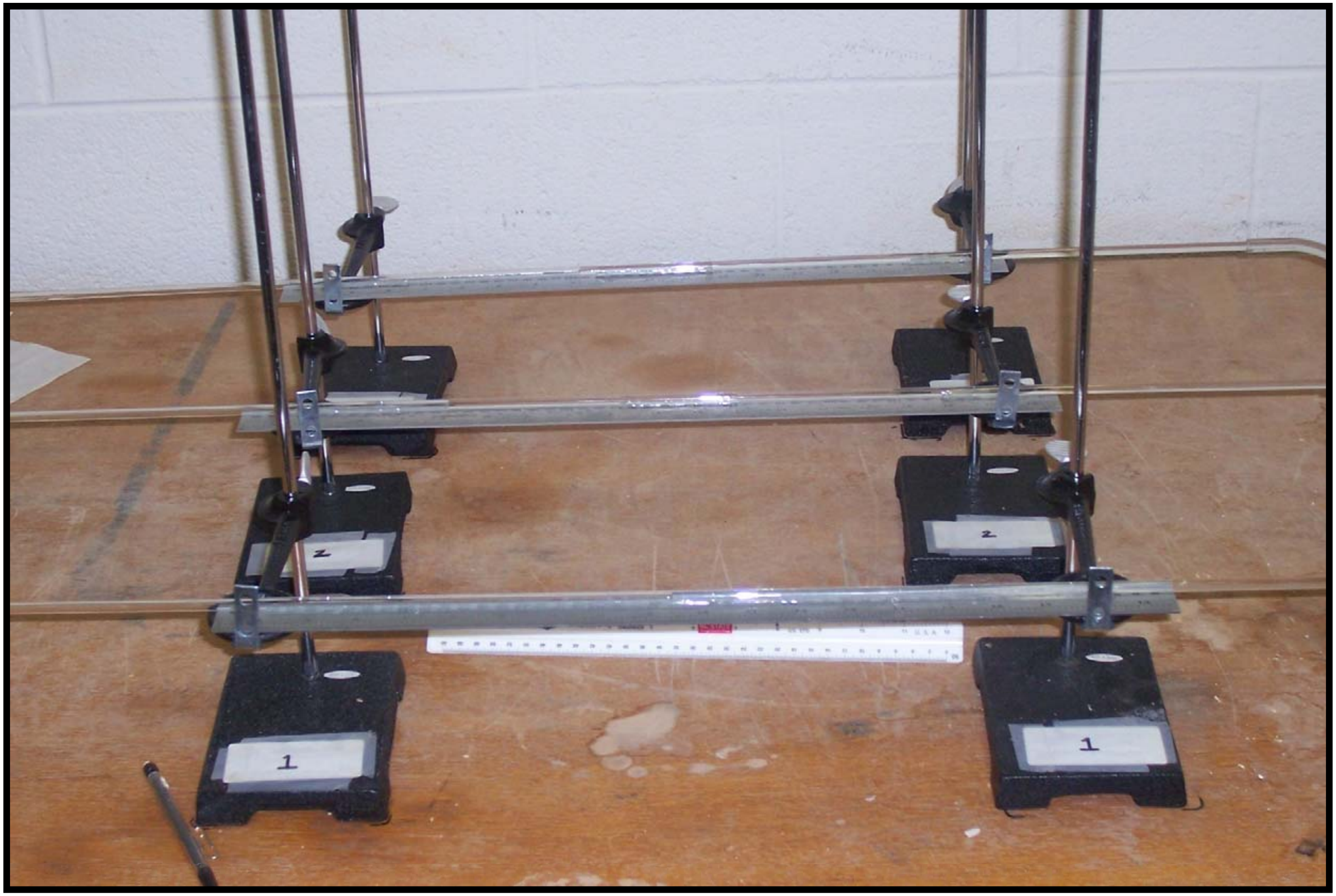
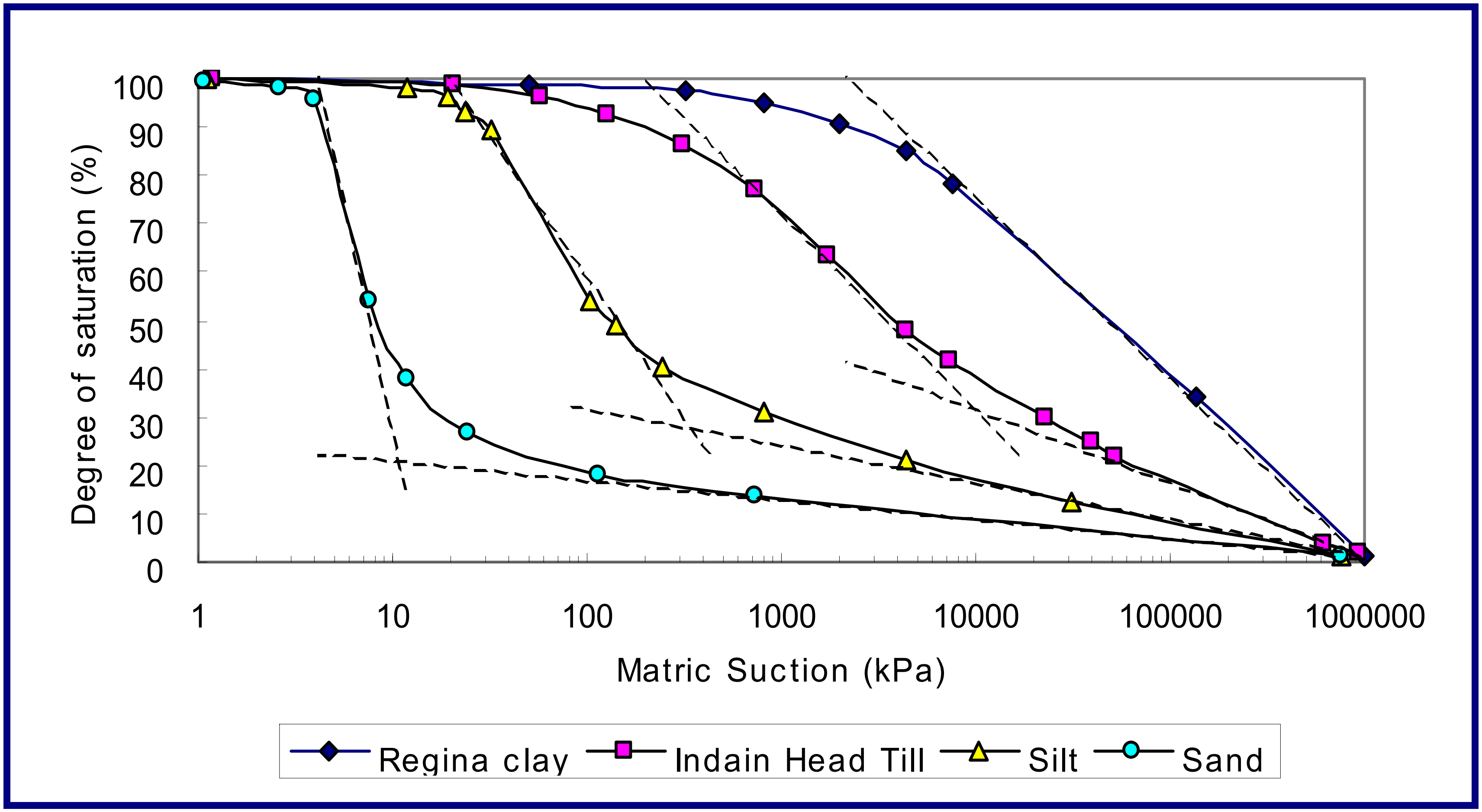
Pressure Plate Test (ASTM 2325)



(NC State University Soils Lab)

Typical SWCCs for Various Soils



(Vanapalli et al., 1999)

Estimation of SWCC

- Experimental determination of SWCC is generally difficult, time-consuming and relatively expensive.
- SWCC could be reasonably estimated from :
  - Fredlund et al model (2002) : grain size distribution
  - Zapata et al model (1999) : grain size distribution (D60), Plastic Index, % 200 passing
  - SoilVision : a database system for Saturated/Unsaturated soil properties for 6,200 soil samples (98% of them have a SWCC measured in the lab)
  - NCHRP 9-23a : a national catalog of subgrade SWCC default inputs for use with MEPDG

Prediction Methods

- **Fredlund et al.'s approach (1996)**

$$\tau_f = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)[\left(\theta^{\kappa}\right)(\tan\phi^{'})]$$

$$where,\ \kappa = -0.0016 \cdot I_P^2 + 0.0975 \cdot I_P + 1$$

- **Vanapalli et al.'s approach (1996)**

$$\tau_f = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)[(\tan\phi^{'})\left(\frac{S - S_r}{100 - S_r}\right)]$$

- **Khallili and Khabbaz model (1998)**

$$\tau_f = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)_f[\chi(\tan\phi^{'})]$$

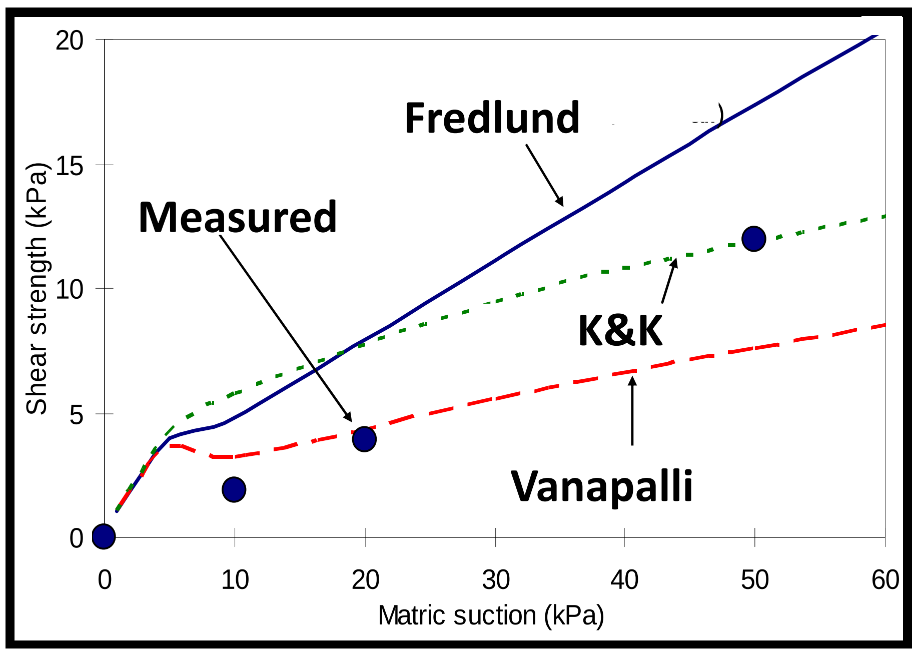
$$where,\ \chi = \left(\frac{(u_a - u_w)_f}{(u_a - u_w)_b}\right)^{-0.55} \quad for\ (u_a - u_w) > (u_a - u_w)_b$$

$$\chi = 1 \quad for\ (u_a - u_w) < (u_a - u_w)_b$$

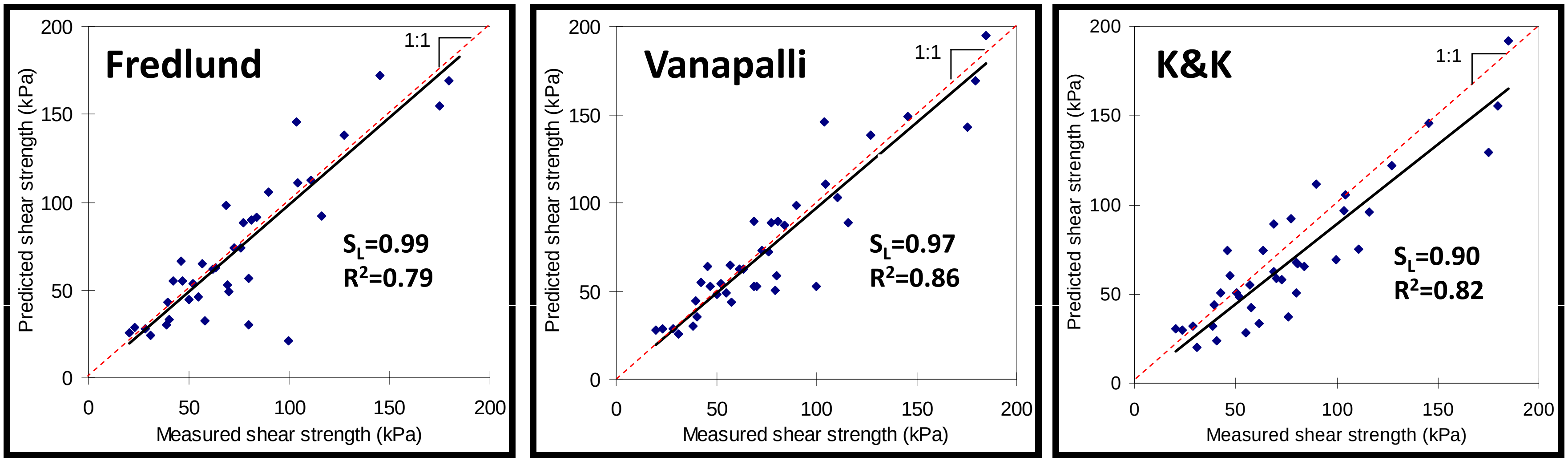
Kim and Borden Study (2011)

- Each of the procedures was developed based on limited experimental data obtained from a few soils
- Comparisons between measured and predicted values of unsaturated shear strength are presented for different soil types (sandy soil, low plasticity soil, silts, etc.)

- o Shear strength data of fifteen soils published in the literature (soils A thru O)
- o Net normal stress (0-200kPa)
- o Matric suction (0-1500kPa)

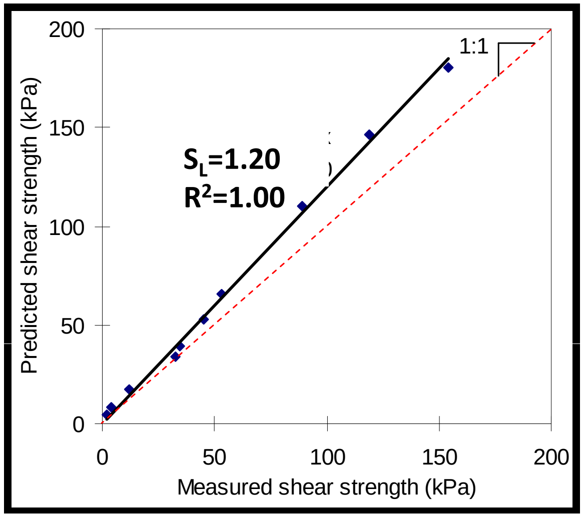


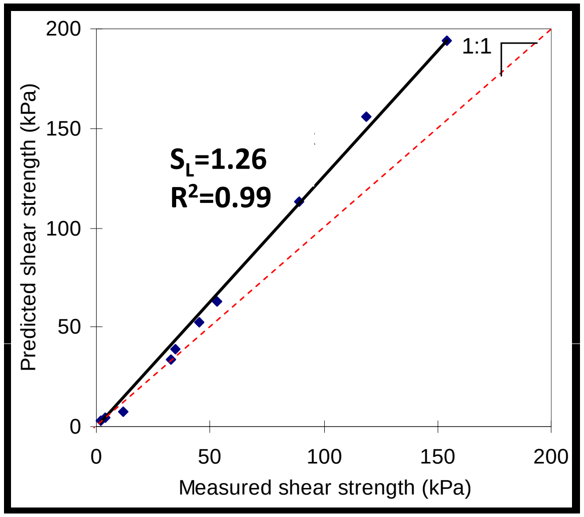
Low Plasticity Clays

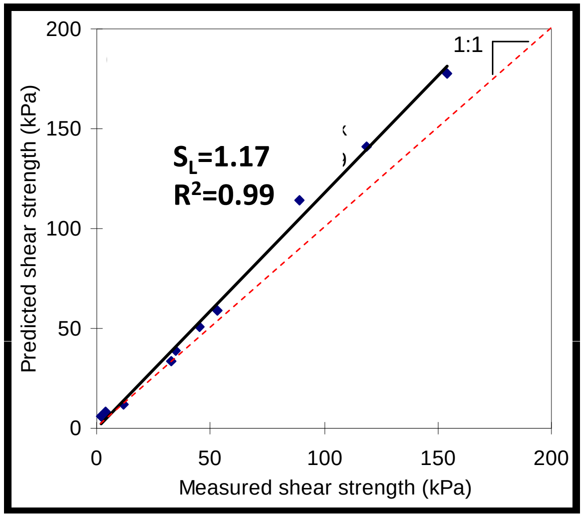


(Kim and Borden, 2011)

Sandy Soils







(Kim and Borden, 2011)

APPLICATION OF UNSATURATED SOIL SHEAR STRENGTH

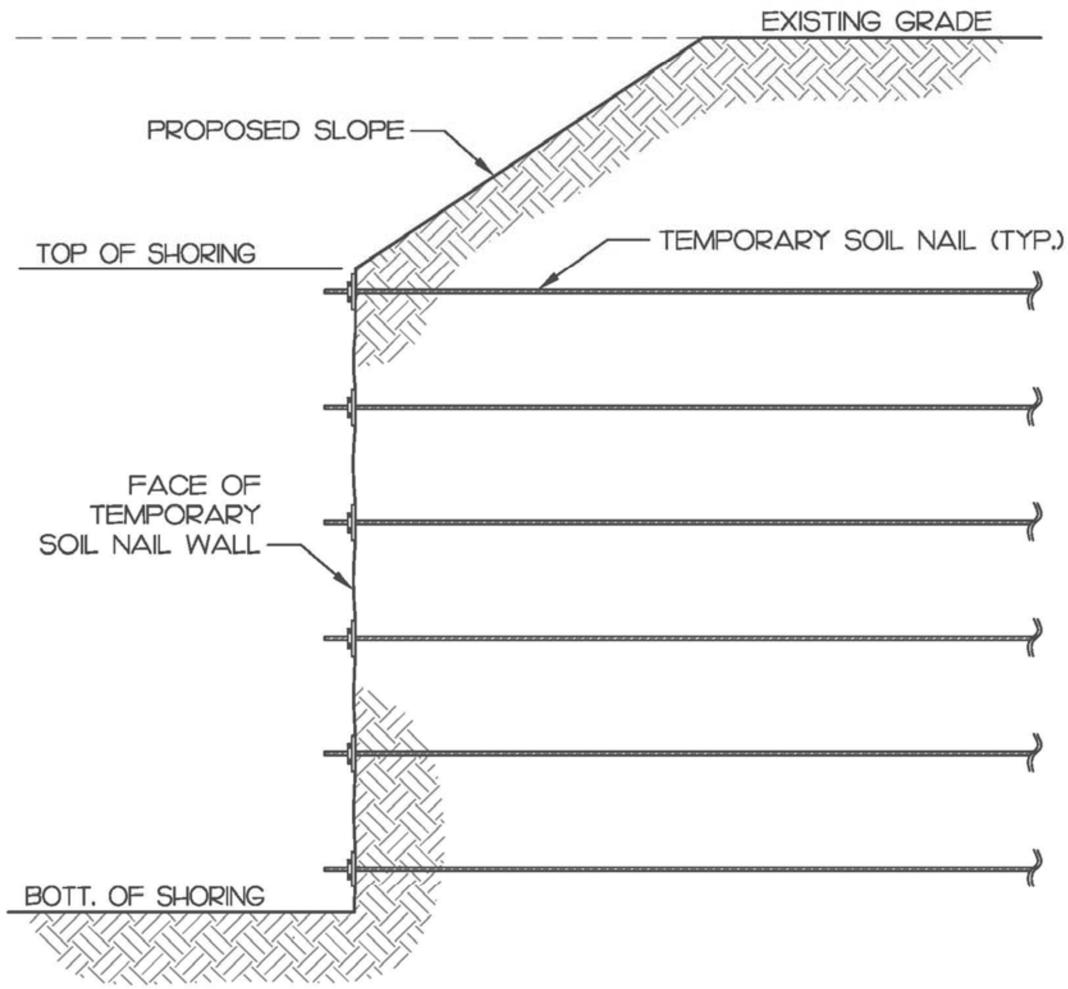
PROJECT SUMMARY

Project : Art Commons at University of North Carolina

Location : Chapel Hill, North Carolina

Shoring Method : Temporary Soil Nail Wall

Soil Description : Silty SAND or Clayey Sandy SILT



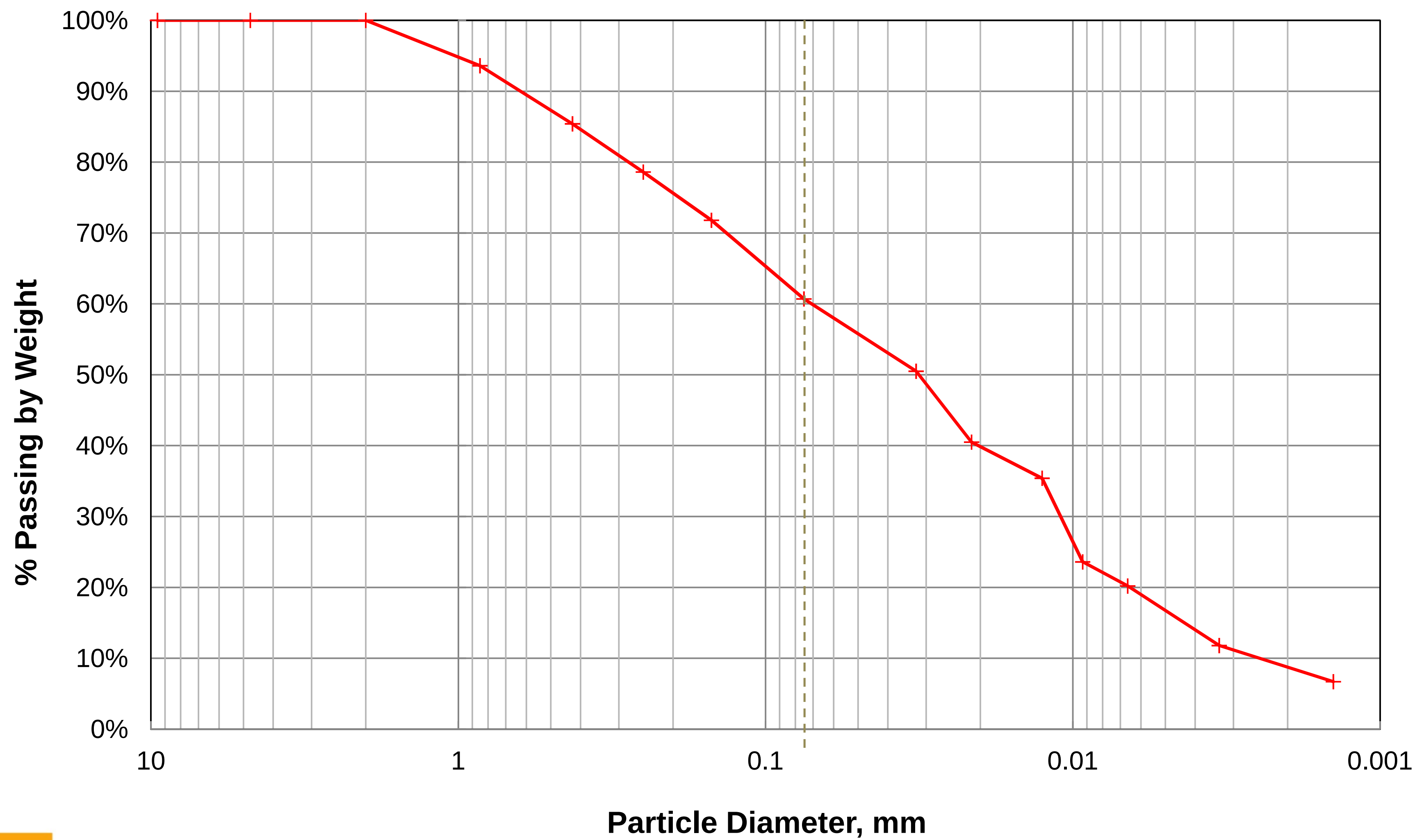
TYPICAL SECTION

NOT TO SCALE

PREPARATION OF SUBSURFACE INFORMATION

1. Five additional soil borings were done.
2. Soil samples were collected from various depths at boring locations.
3. Additional tests were performed on sampled soils.
4. Locations of all nearby utilities were carefully reviewed.

GRAIN SIZE DISTRIBUTION CURVE OBTAINED

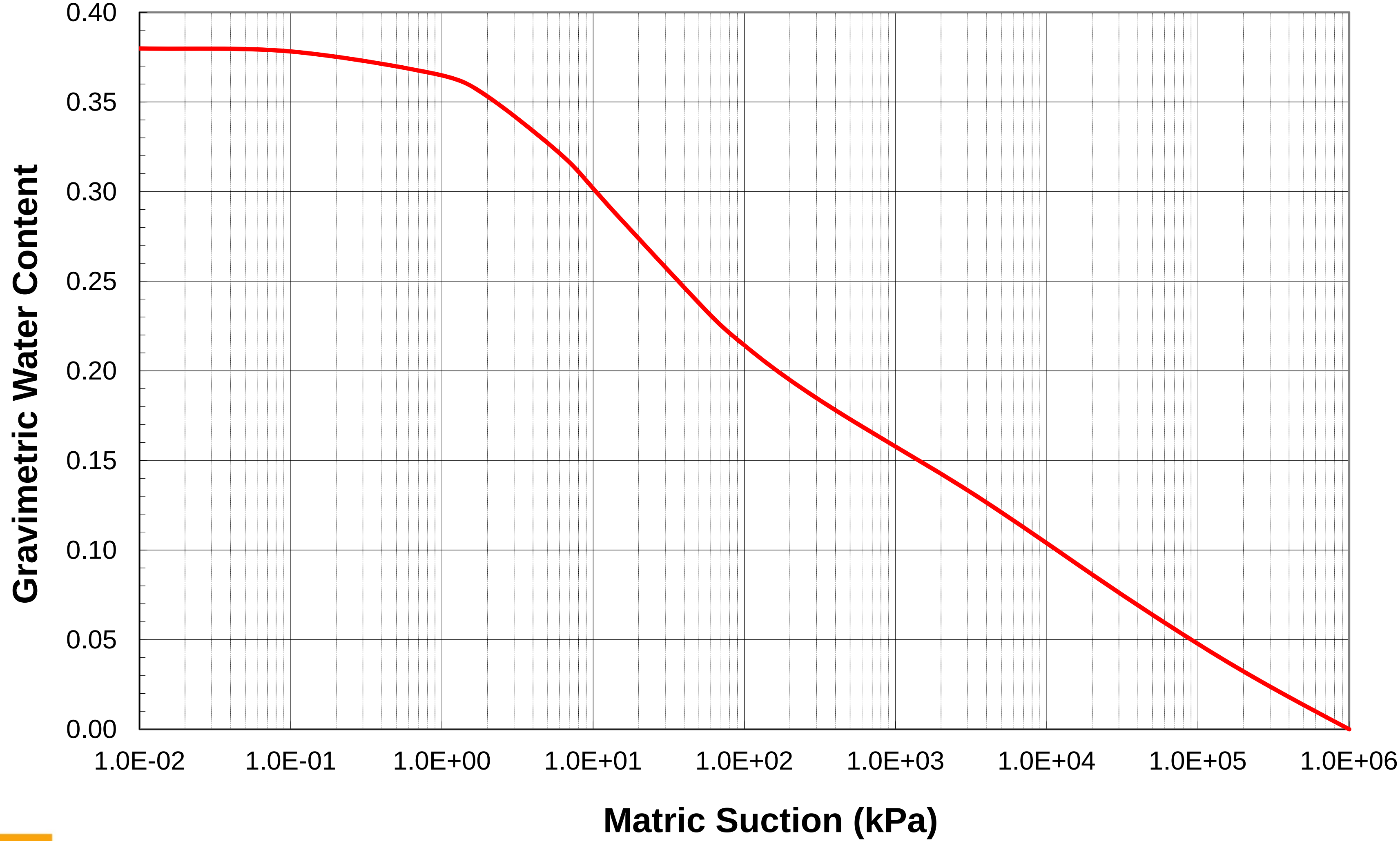


SOILVISION

A Knowledge-Based Database System for Saturated / Unsaturated Soil Properties

SOILVISION is a knowledge-based database software including unsaturated soil data on over 6,200 soil samples. 98% of these soil samples have a soil-water characteristic curve measured in a laboratory. These data are used to estimate unsaturated soil properties.

SWCC OBTAINED FROM SOILVISION



SHEAR STRENGTH PREDICTION METHODS

- **Fredlund et al.'s approach (1996)**

$$\tau_f = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)[\left(\theta^{\kappa}\right)(\tan\phi')]$$

$$where,\ \kappa = -0.0016 \cdot I_P^2 + 0.0975 \cdot I_P + 1$$

- **Vanapalli et al.'s approach (1996)**

$$\tau_f = c' + (\sigma_n - u_a)\tan\phi' + (u_a - u_w)[(\tan\phi')\left(\frac{S - S_r}{100 - S_r}\right)]$$

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$$where,\ \chi = \left(\frac{(u_a - u_w)_f}{(u_a - u_w)_b}\right)^{-0.55} \quad for\ (u_a - u_w) > (u_a - u_w)_b$$

$$\chi = 1 \quad for\ (u_a - u_w) < (u_a - u_w)_b$$

COMPARISON OF TOTAL COHESIONS OBTAINED

- per Fredlund et al.'s approach → 14.5 kPa
- per Vanapalli et al.'s approach → 14.5 kPa
- Khallili & Khabbaz's approach → 14.6 kPa

Some soils showed much great differences in total cohesions calculated from three approaches.

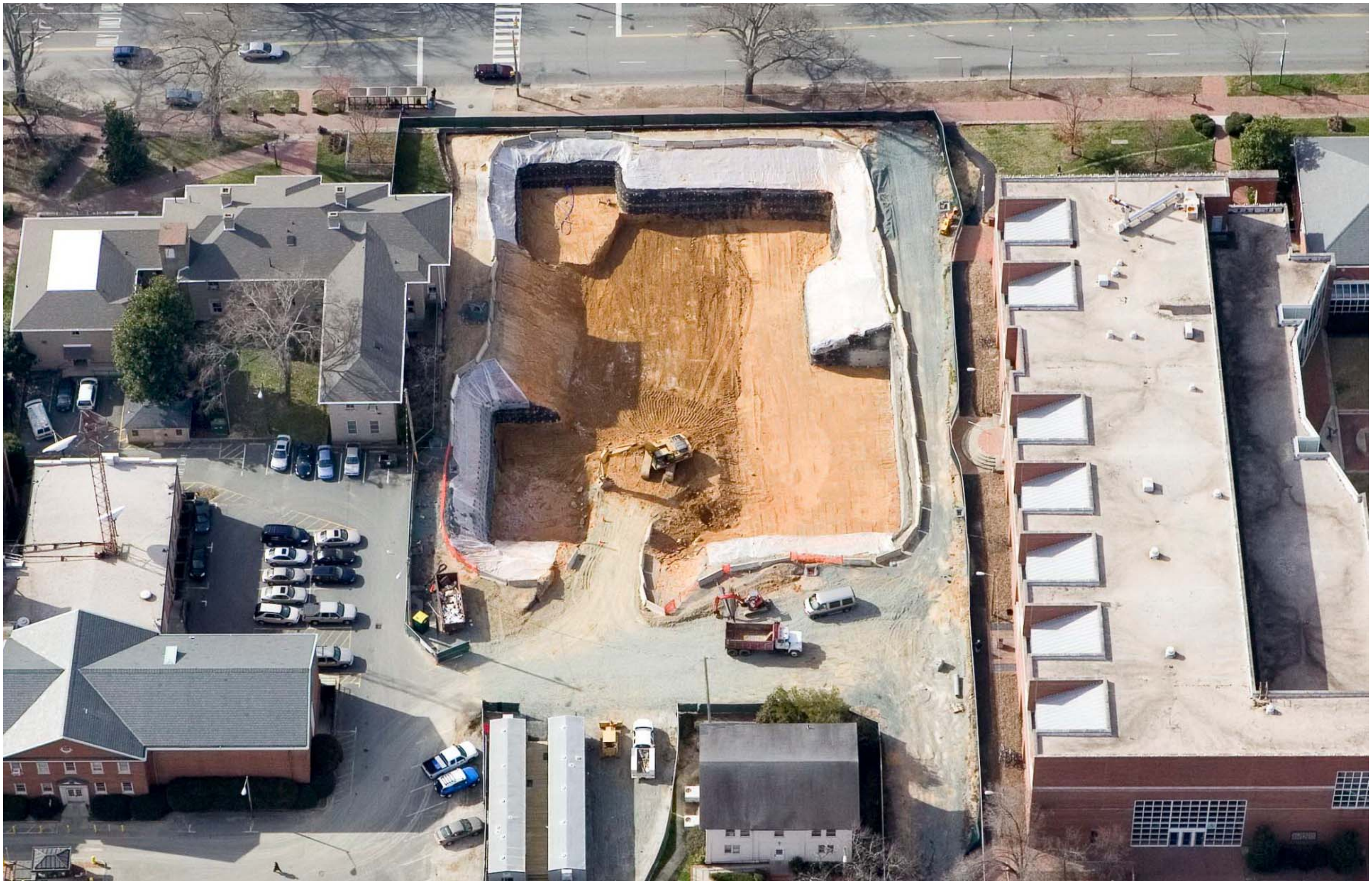
CONSTRUCTING TEMPORARY SOIL NAIL WALL

COMPLETED TEMPORARY SOIL NAIL WALL

Subsurface

Subsurface Construction Company

AERIAL PHOTO OF PROJECT SITE AFTER COMPLETION



PROJECT SUMMARY

Project : Wake County Parking Deck

Location : Raleigh, North Carolina

Shoring Method : Temporary Soil Nail Wall

Soil Description : Silty SAND or Sandy SILT

PLASTIC COVER AND SUPPLEMENTAL DRILLED SOIL NAIL

ENCOUNTERING ROCK DURING DRIVEN SOIL NAIL INSTALLATION

Subsurface

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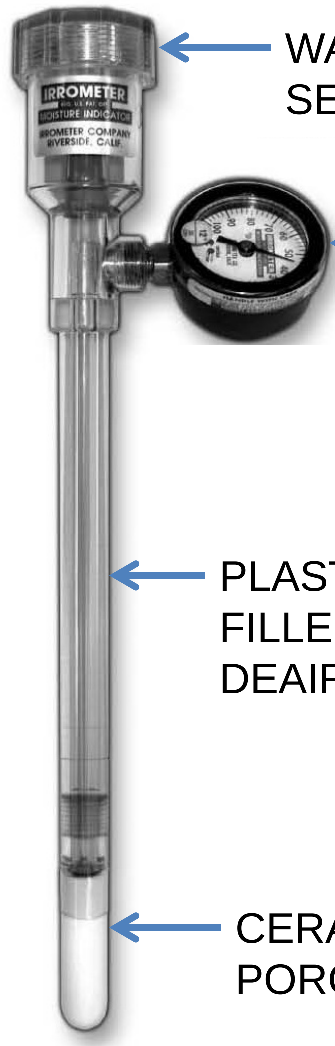

TENSIOMETER

1. Negative pore-water pressure in soil can be directly measured.
2. The measured negative pore-water pressure is numerically equal to the matric suction when the pore-air pressure is atmospheric (i.e., $u_a = 0$).
3. The measuring capacity is limited to 100 kPa.

USE OF TENSIOMETER TO MEASURE ACTUAL MATRIC SUCTION

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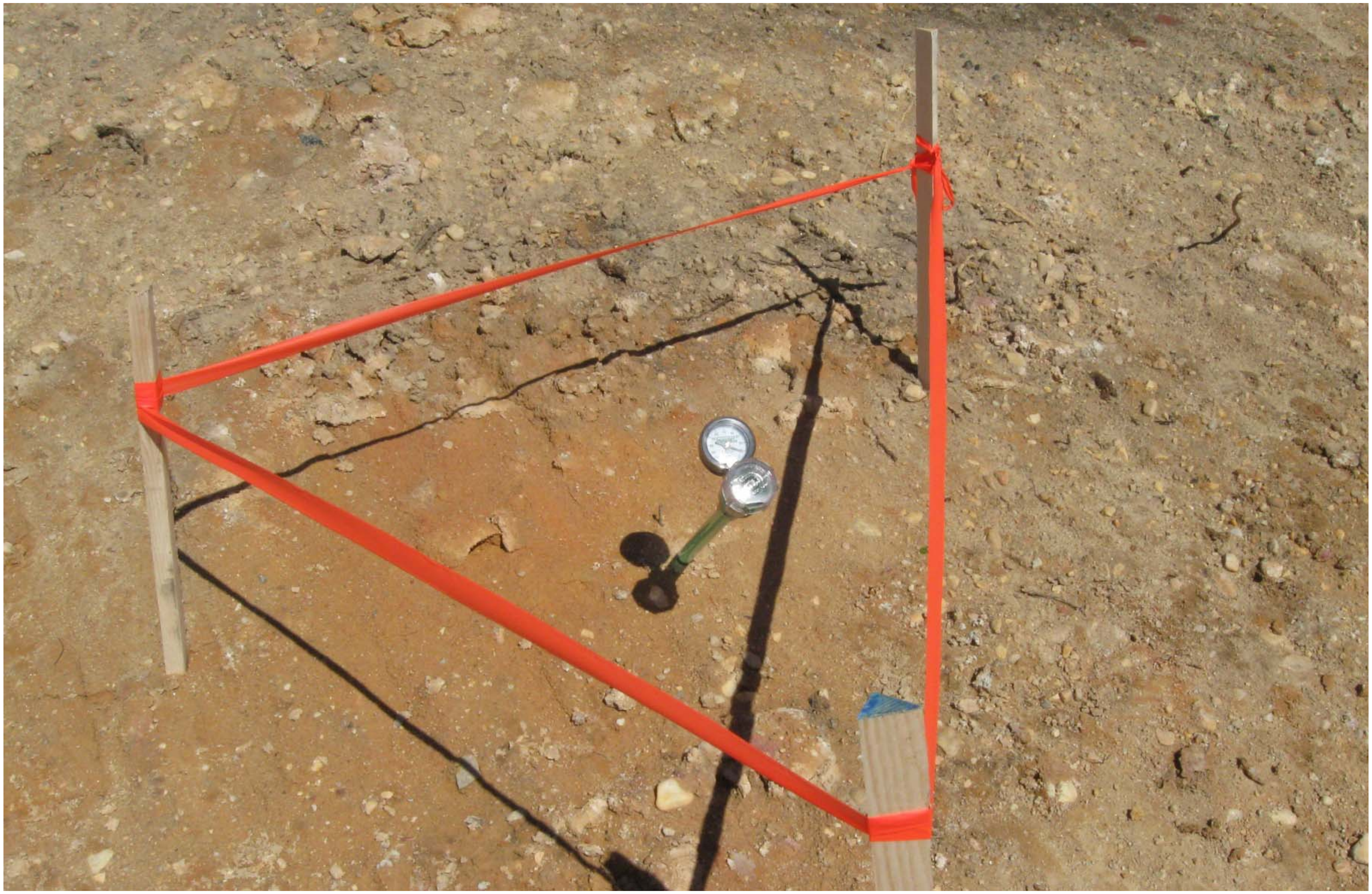

USE OF TENSIOMETER TO MEASURE ACTUAL MATRIC SUCTION

SHORTCOMINGS FOUND DURING THIS PRACTICE

1. How can the Soil Water Characteristic Curve obtained from SOILVISION software be confirmed for site specific soils?

2. How can moisture content (or matric suction) be confirmed during the project life?

3. Which shear strength prediction method is most appropriate to use?

CONCLUSIONS

1. Unsaturated soil shear strength properties estimated with information from additional soil tests and SOILVISION software have been used to design temporary soil nail wall.

2. Special care needs to be taken for control of natural moisture content (or matric suction) in soil (*i.e.* surface water run-off, ground water and etc.).

3. Studies on shortcomings found during this projects should be explored for more confident and wider use.

Thank you!

CONTACT

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