Measurements of Soil Suction

Total suction

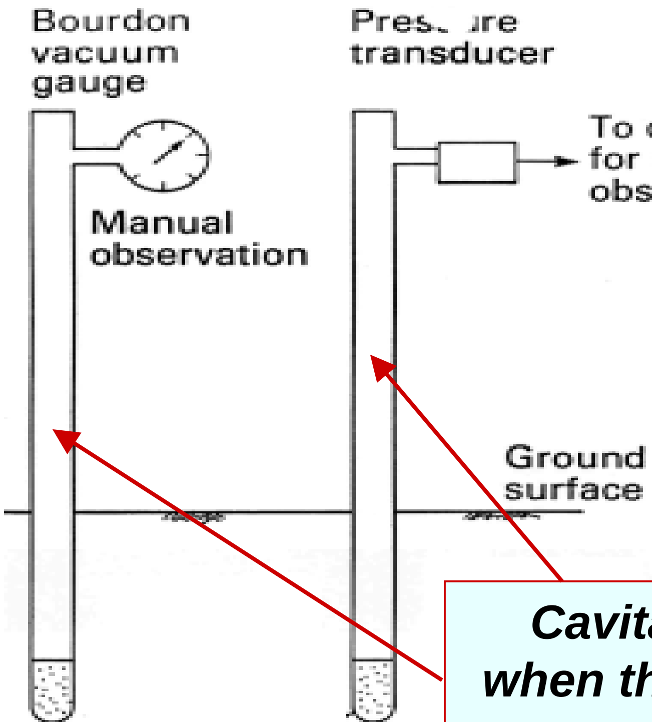
Matric suction

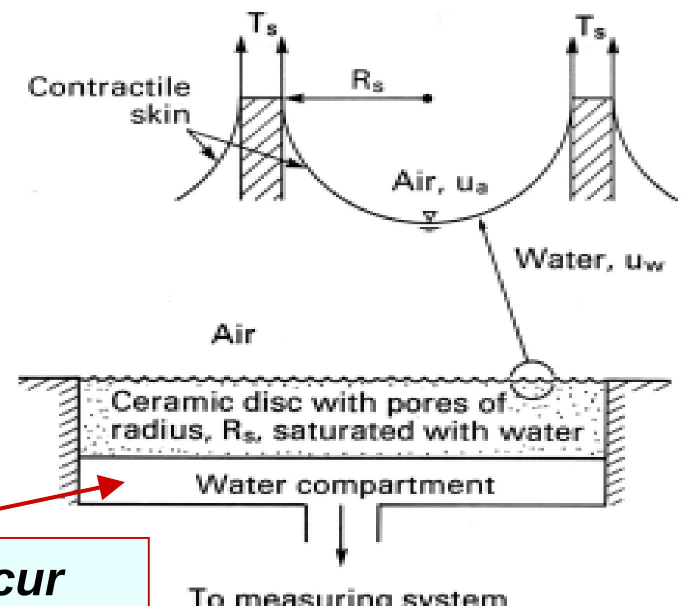
Direct high matric suction measurements

Osmotic suction

Unsaturated Soil Technology

The Primary Need is to Measure Matric Suction in Geotechnical Engineering but it is Difficult to Extend the Range Above 100 kPa





Cavitation can occur when the vapor pressure is reached

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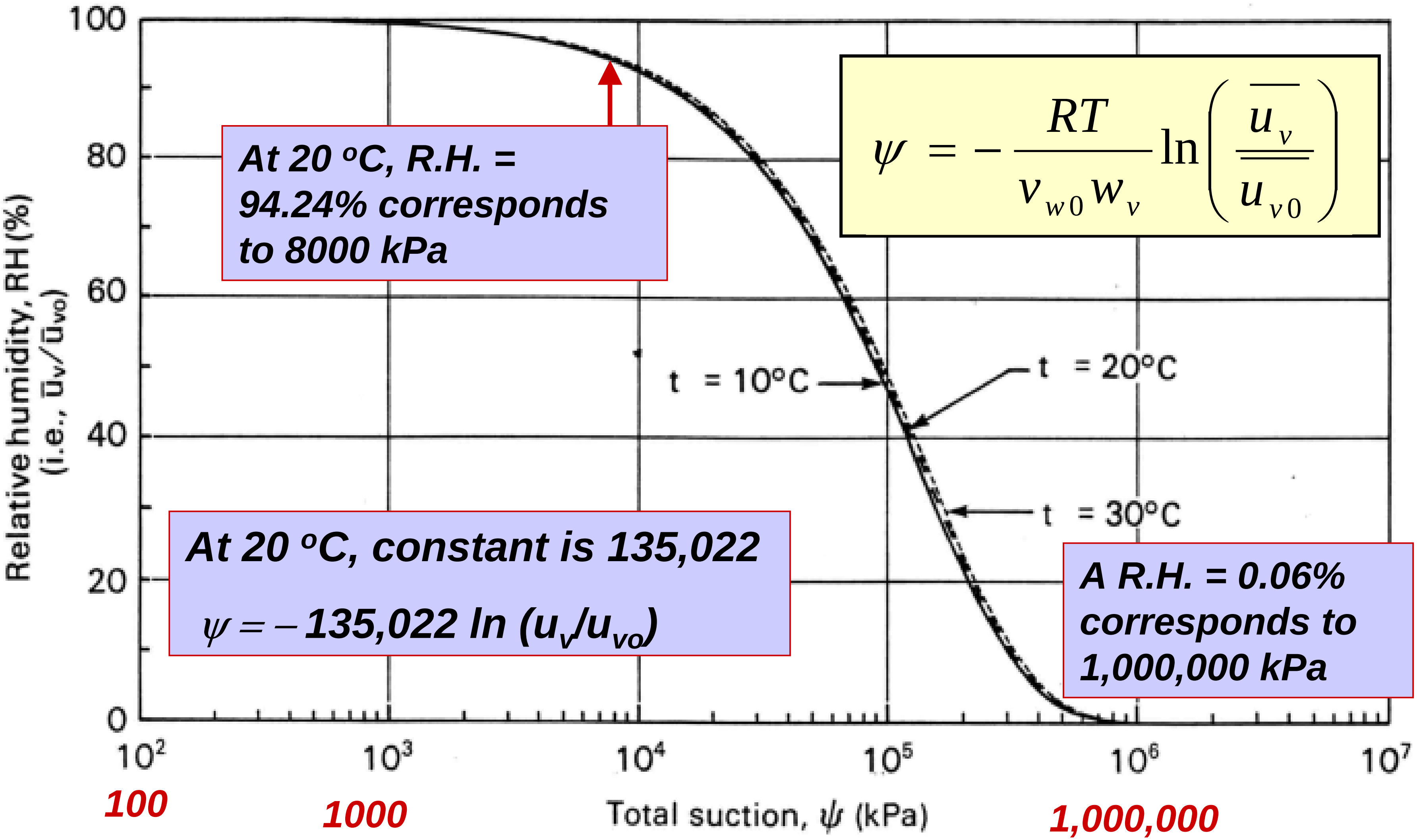
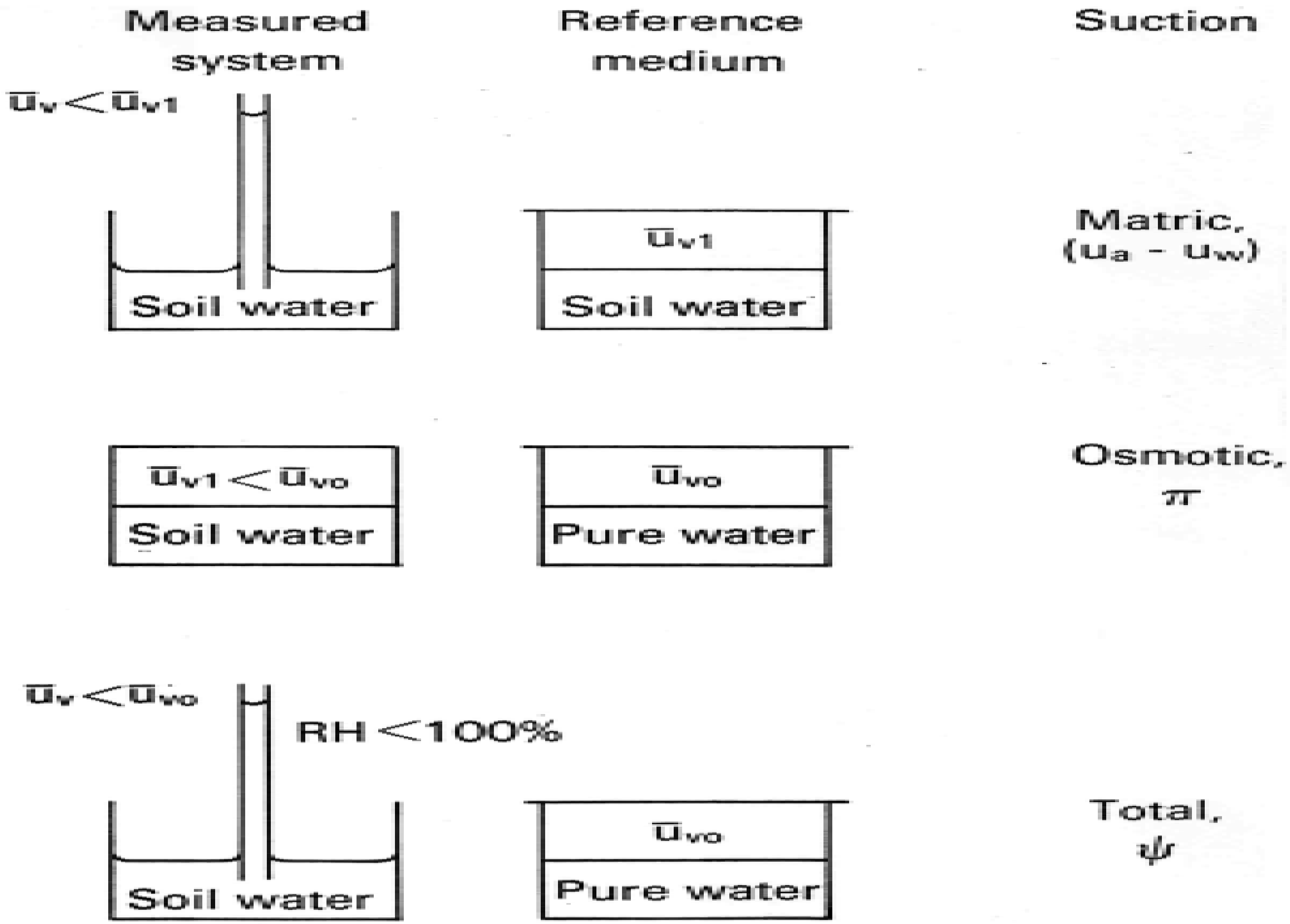
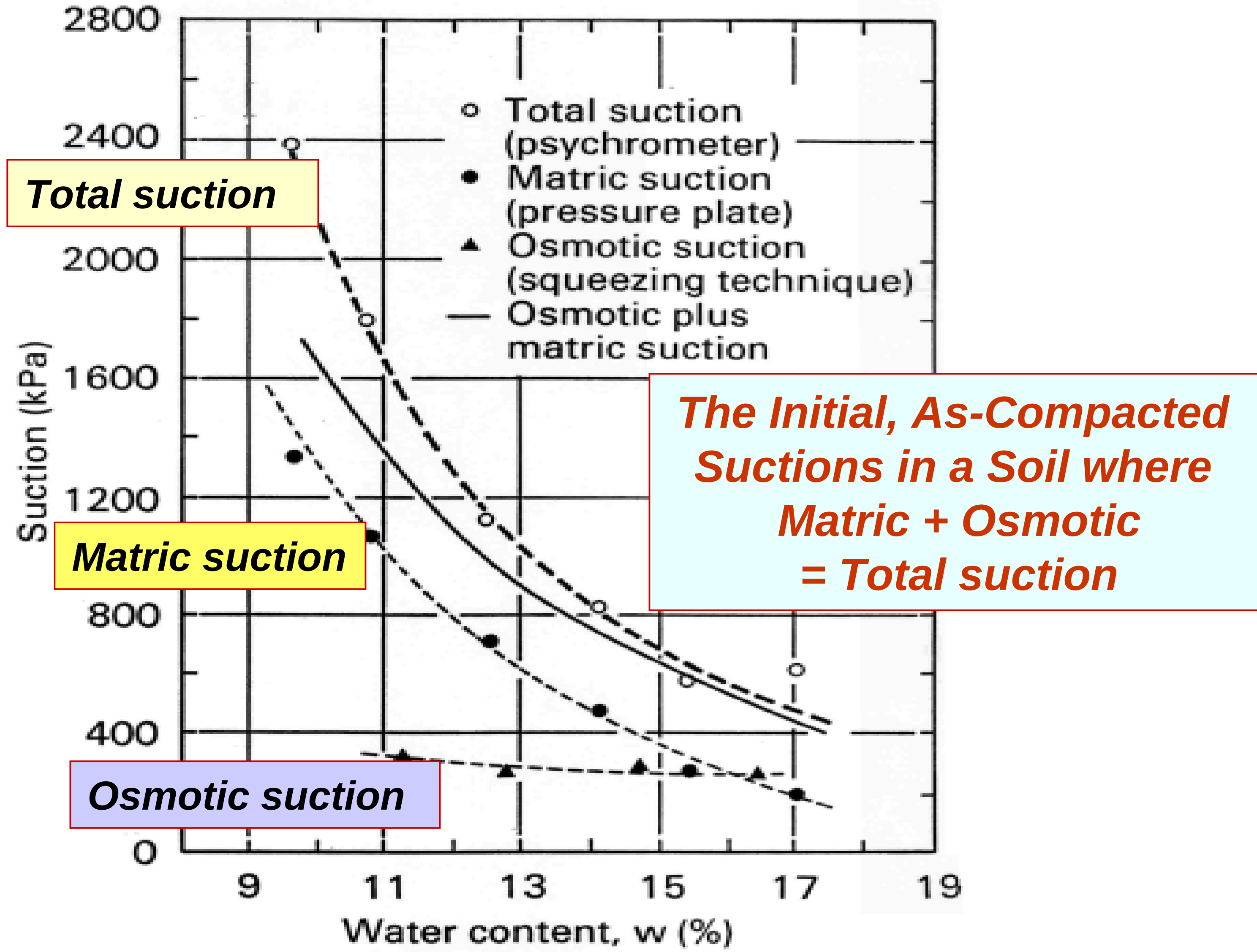


Relative humidity versus total suction relationship



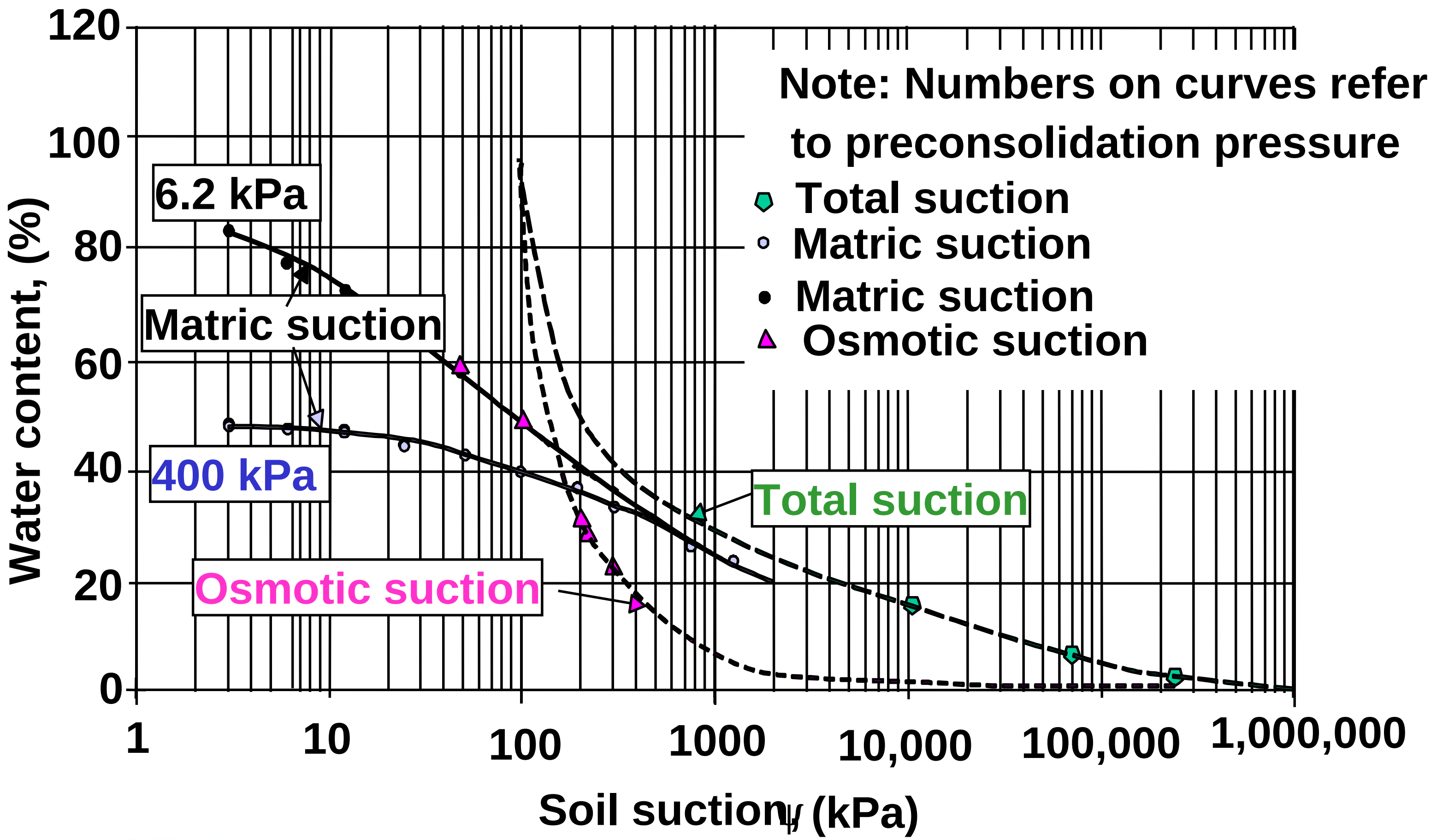
Total suction and its components: matric and osmotic suction

NOTE: This is NOT a SWCC



Total matric and osmotic suctions for glacial till (from Krahn and Fredlund, 1972)

Influence of the Components of Soil Suction In Different Ranges of Suction



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MEASUREMENTS OF TOTAL SUCTION

-Based on establishing an equilibrium condition between the water vapor in the soil and the environment surrounding the soil specimen.

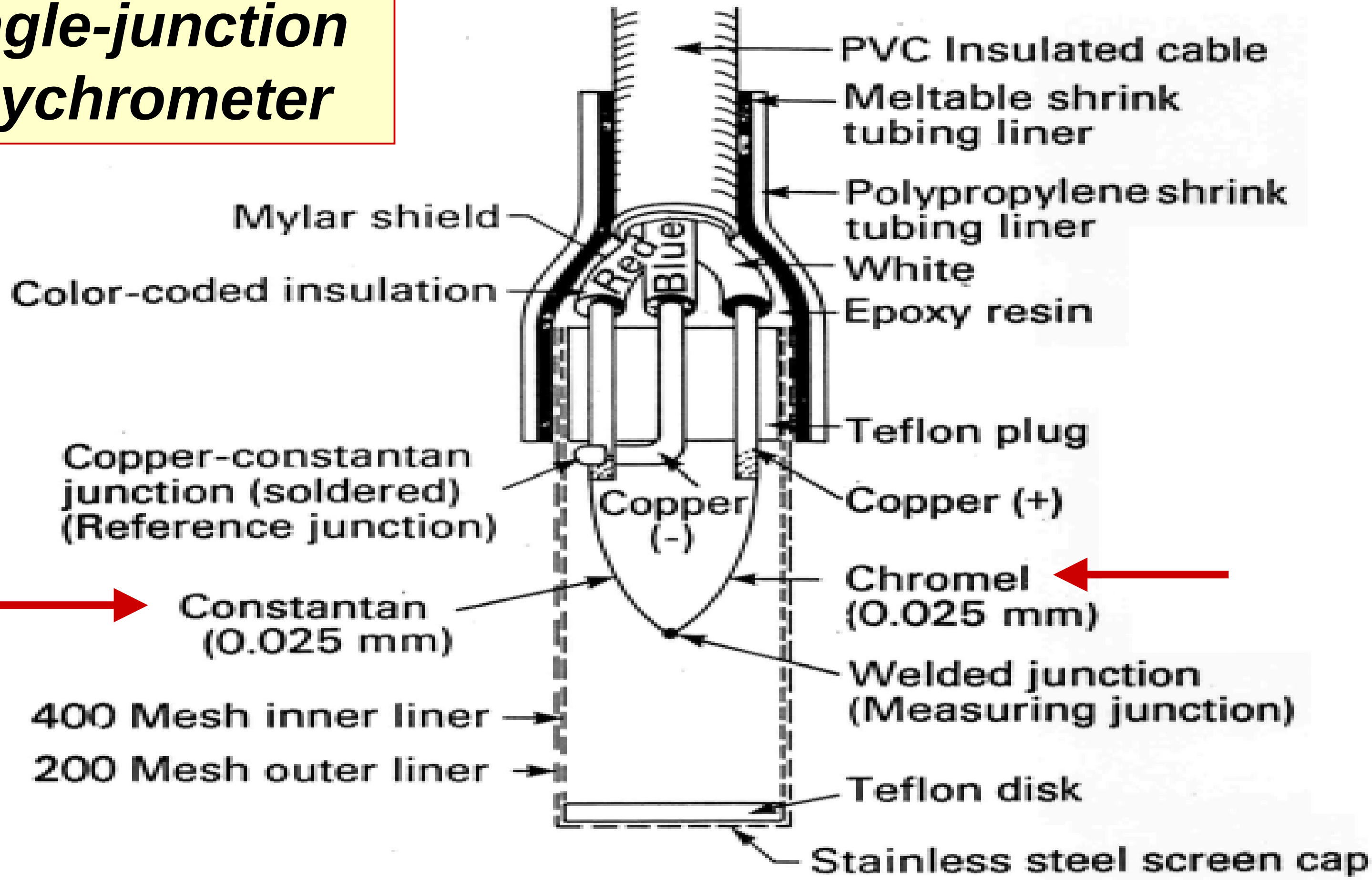
-PSYCHROMETERS (Range 100 – 8000 kPa)

-Measures relative humidity by observing the rate of evaporation of a droplet of water.

-FILTER PAPER (Entire Range of Suctions)

-Measures relative humidity through water content equalization of an absorptive paper.

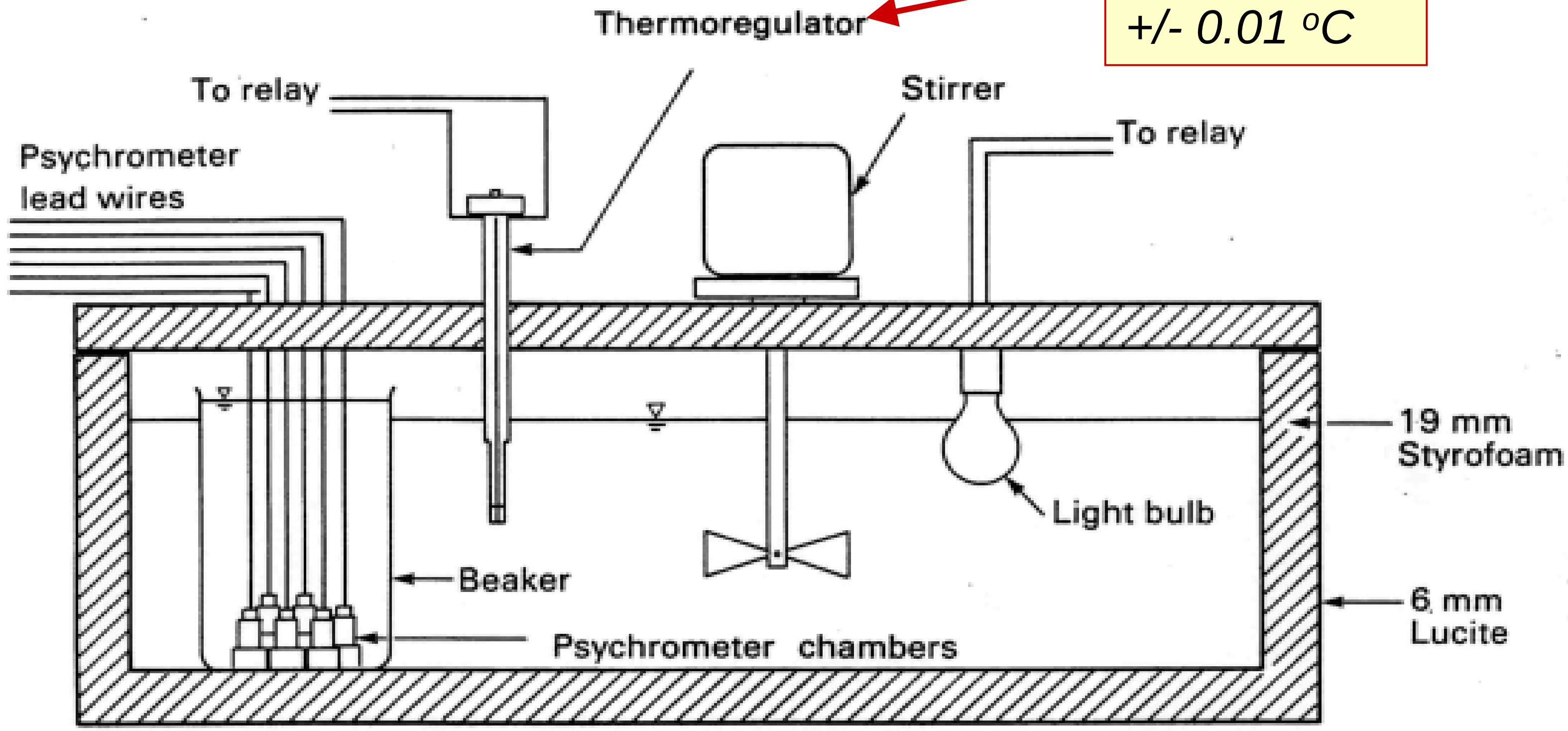
Single-junction Psychrometer



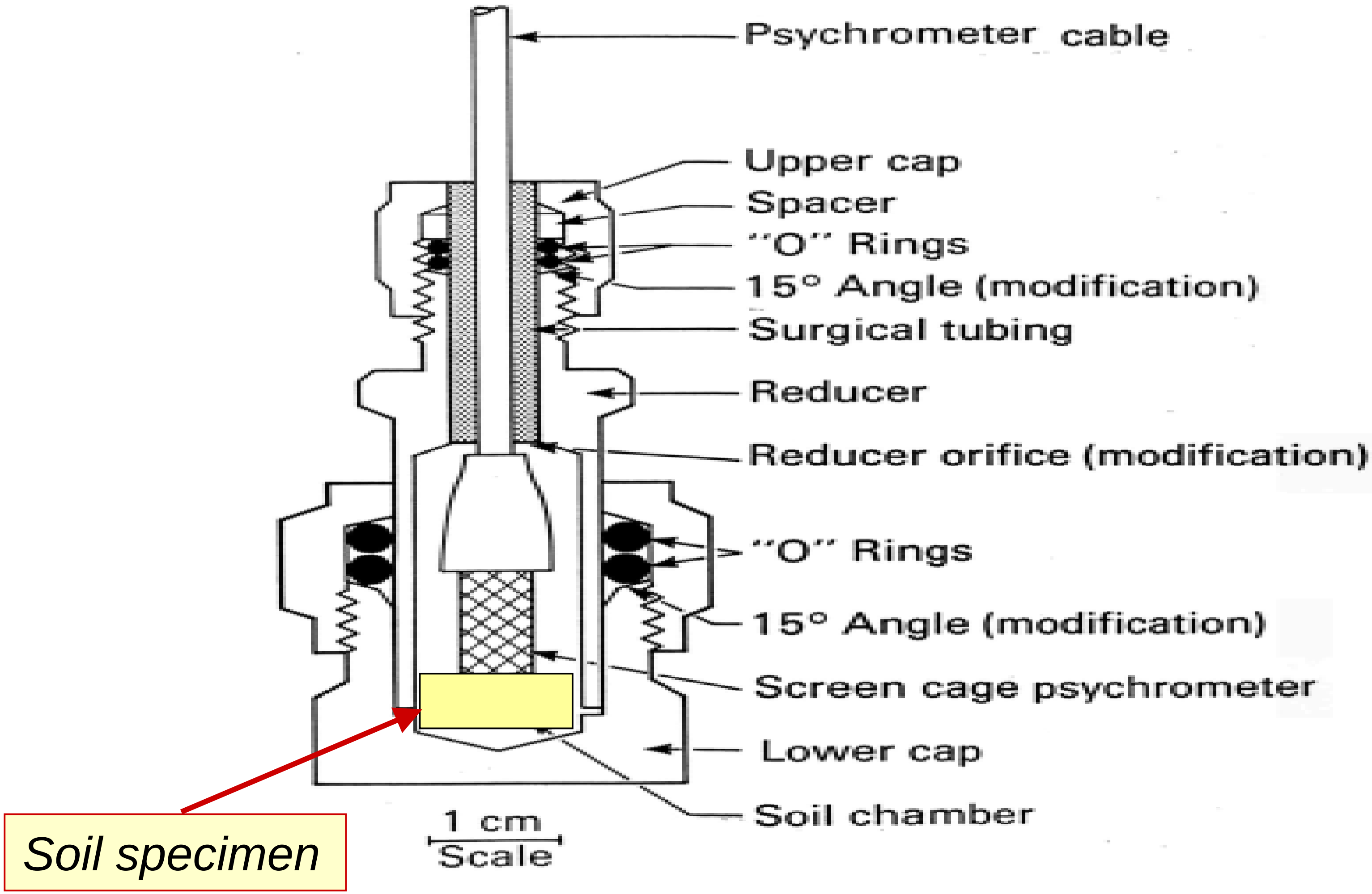
Screen-caged single-junction Peltier thermocouple psychrometer (from Brown and Collins, 1980)

Mainly limited to laboratory usage

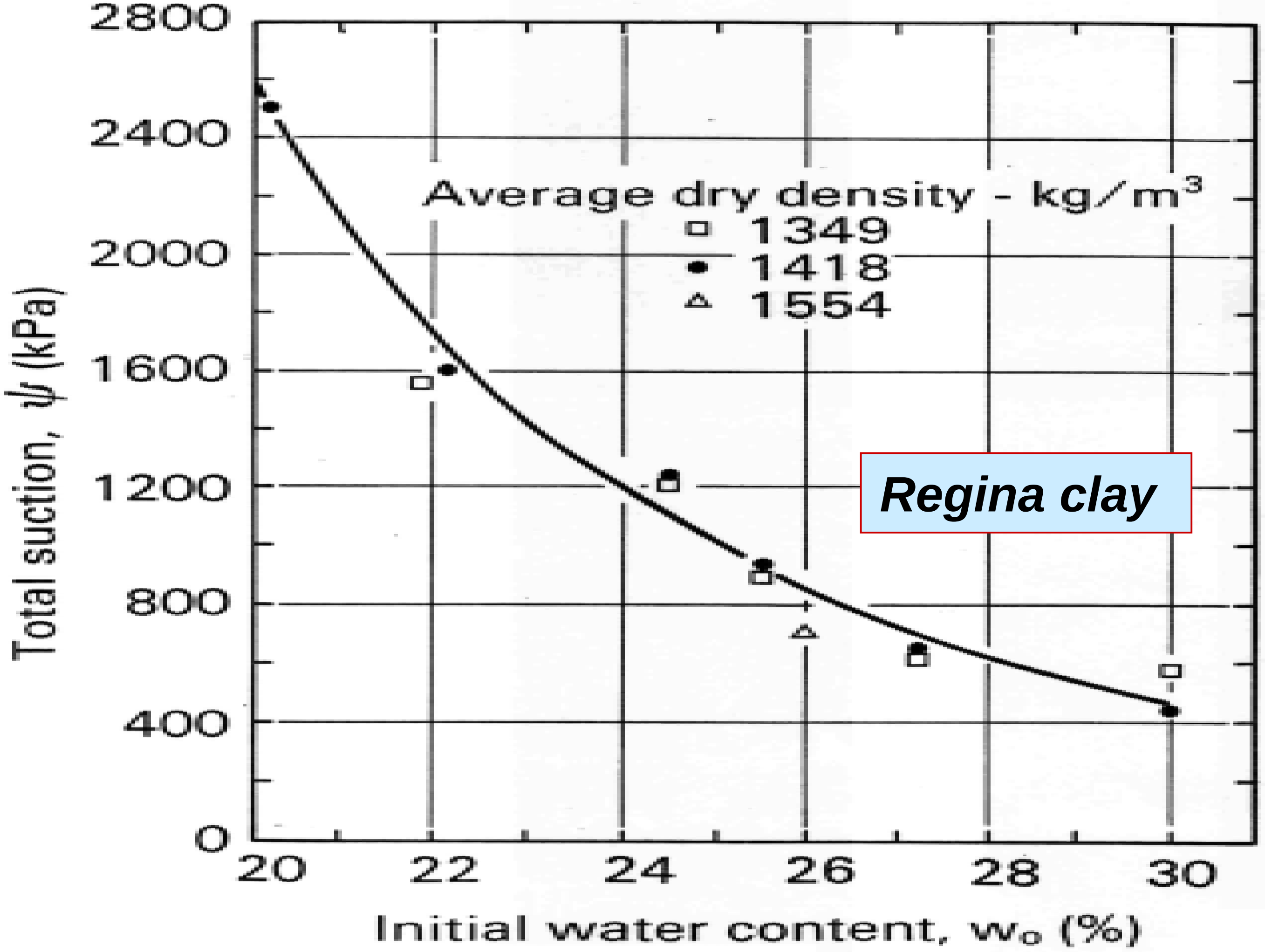
Temperature measured to +/- 0.01 ^{o}C



Constant temperature bath controlled to +/- 0.001 degree Celcius for suction of 100 kPa

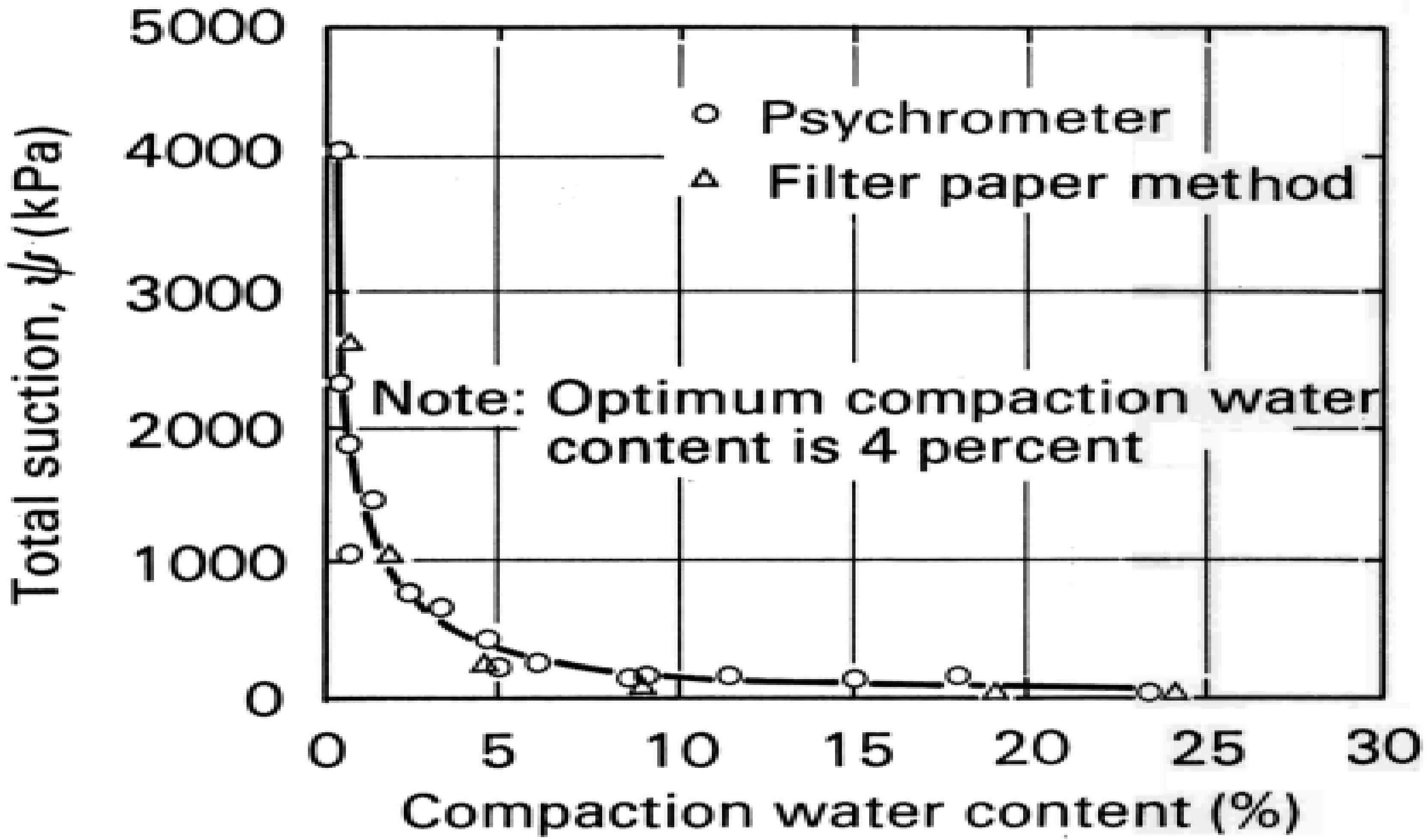


Stainless steel sample chamber with a sealed psychrometer in place (from Brown and Collins, 1980)



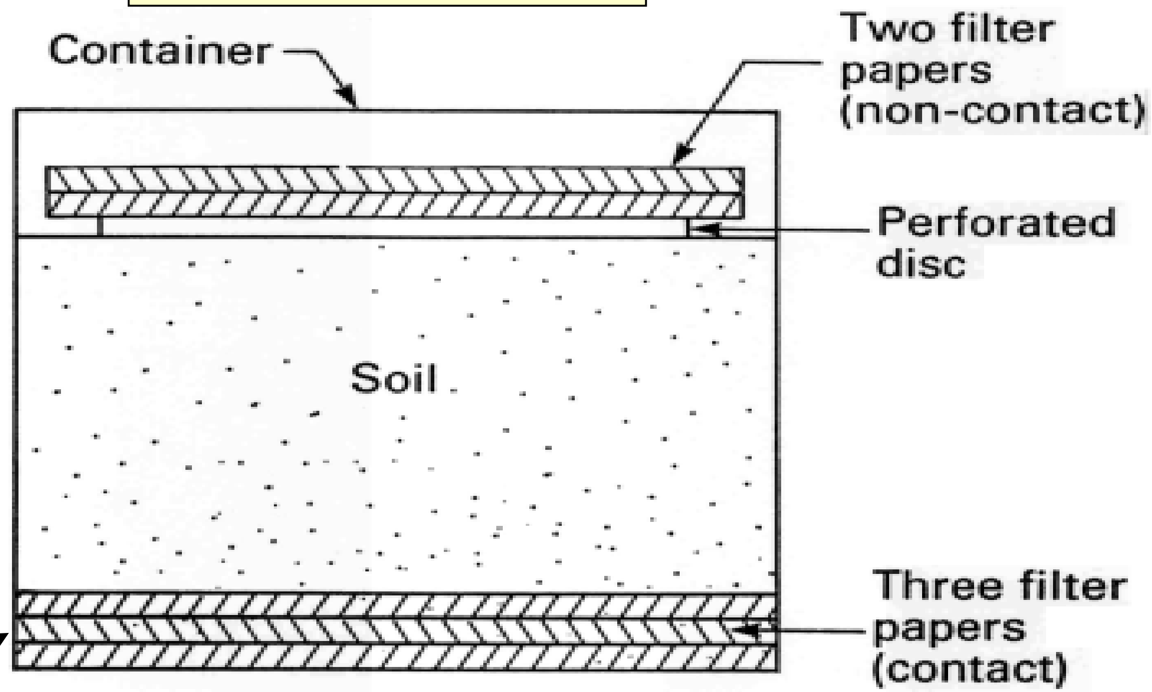
Total suction versus initial water content relationship for Regina clay (from Krahn and Fredlund, 1972)

Accuracy, reproducibility and reliability appear to be quite similar between psychrometers and filter paper



Comparison of independent measurements of total suction on a compacted silty sand (from Daniel, Hamilton and Olson, 1981)

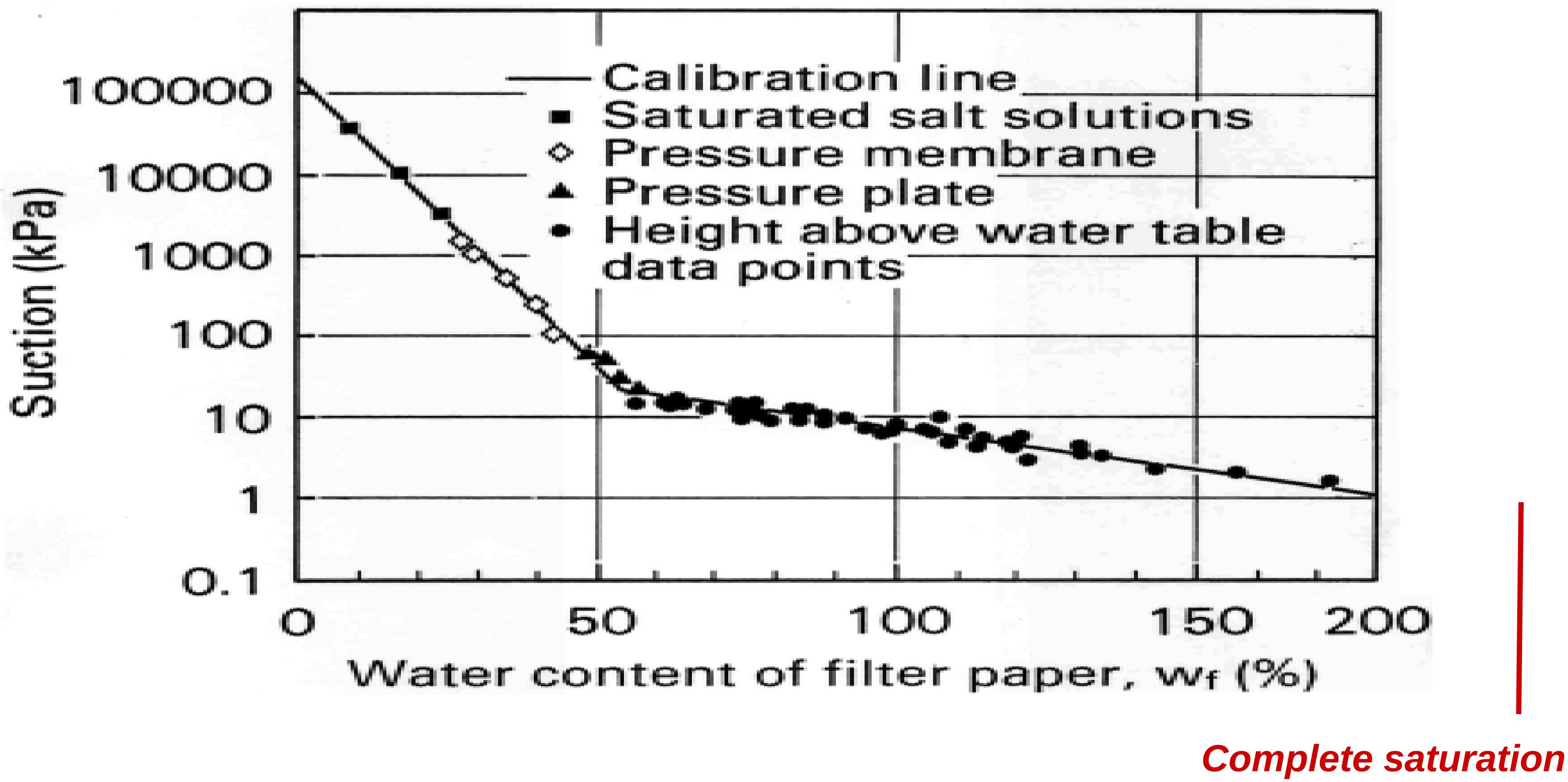
Non-contact filter paper: Total suction



Contact filter paper: Matric suction

Contact and non-contact filter paper methods for measuring matric and total suction, respectively

Calibration curve is actually a Water Retention Curve (i.e., water content versus soil suction) for Filter Paper



A typical calibration curve showing measured water contents for suctions applied to the filter paper (from McQueen and Miller, 1968)

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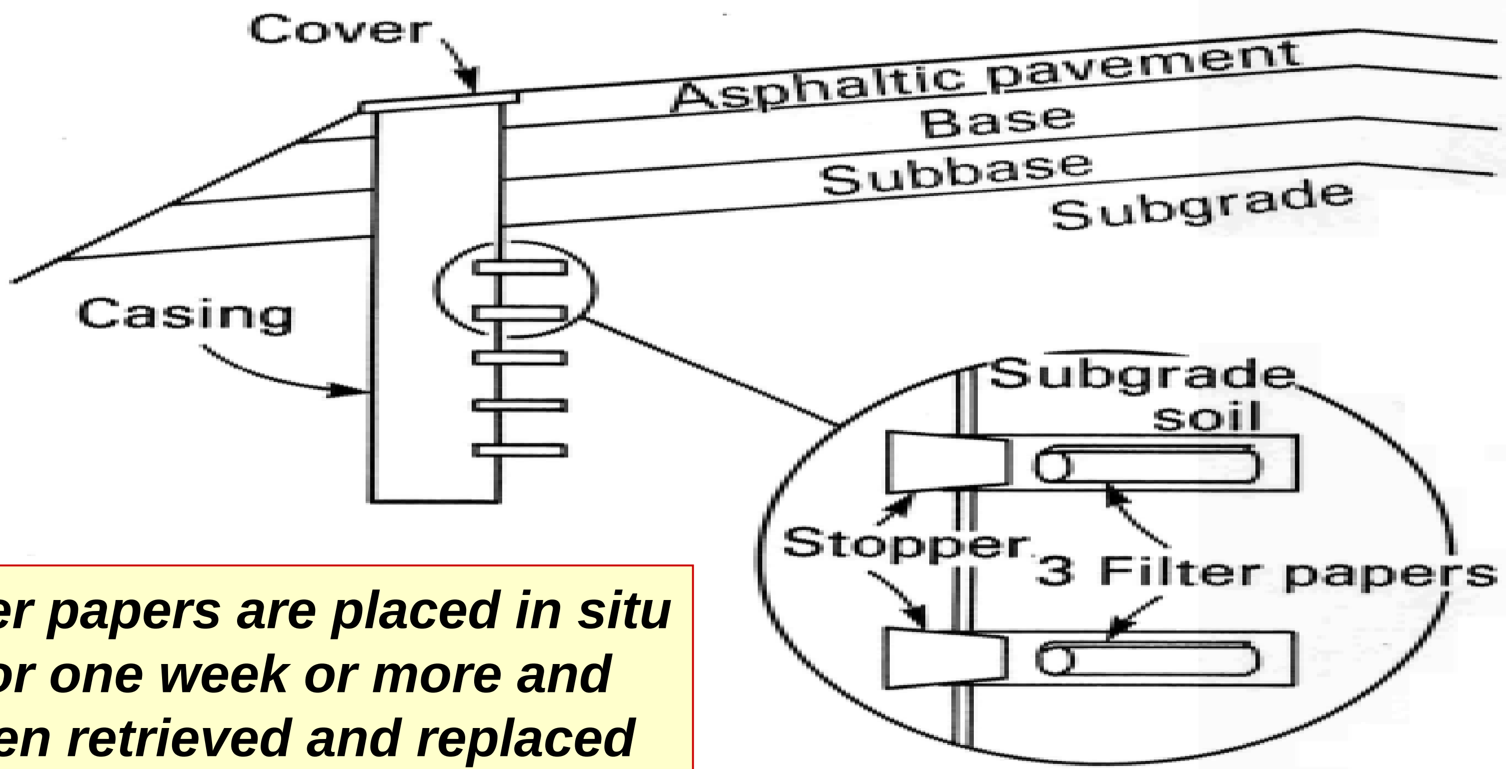


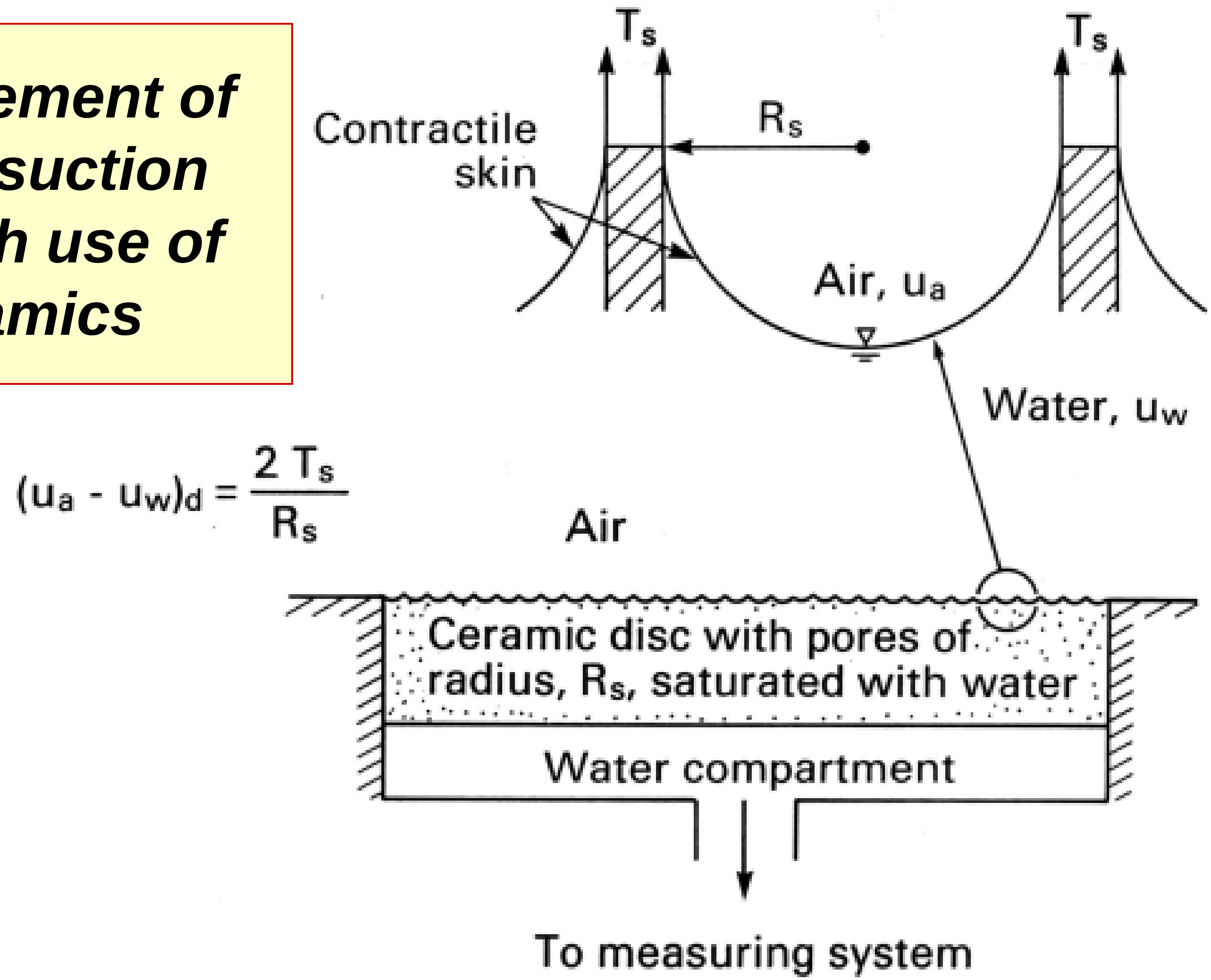
Filter papers are placed in situ for one week or more and then retrieved and replaced with other filter papers

Proposed scheme for using filter papers to measure total suction

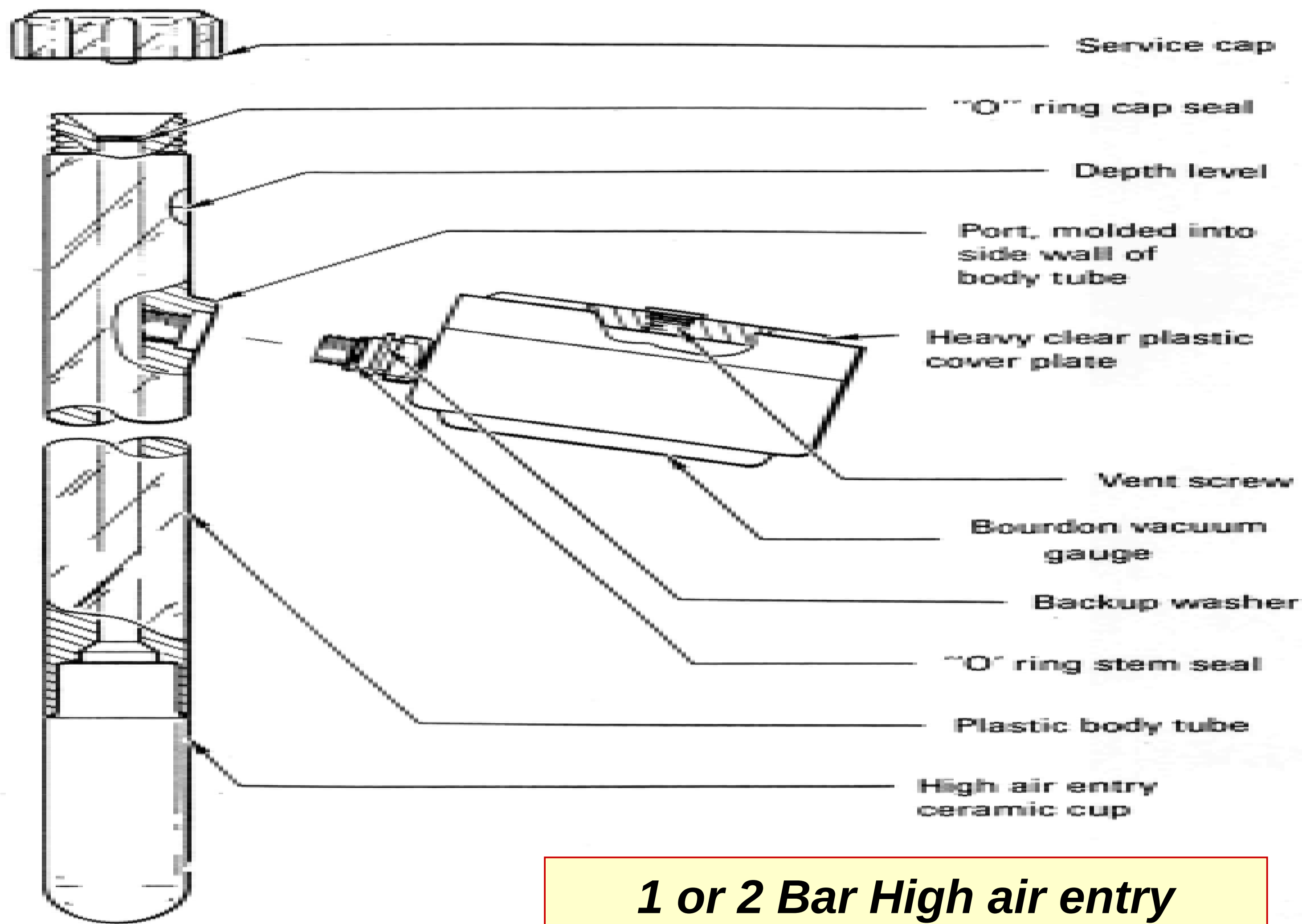
Measurement of Matric Suction

- ***Ceramic disks referred to as high air entry disks are used as separators between air and water***
- ***Ceramic disks are made of sintered kaolin***
- ***Ceramic disks are hydrophyllic in nature and therefore readily saturate with water***
- ***Each ceramic disk has an air entry value below which air cannot pass***
- ***However, air can diffuse through the water in the ceramic disk and is called diffused air***
- ***Synthetic plastic or cow gut can be used as separators up to 15 atmospheres***

Measurement of Matric suction through use of ceramics



Operating principle of a high air entry disc as described by Kelvin's capillary model



1 or 2 Bar High air entry ceramic cup

Conventional tensiometer from Soilmoisture Equipment Corporation

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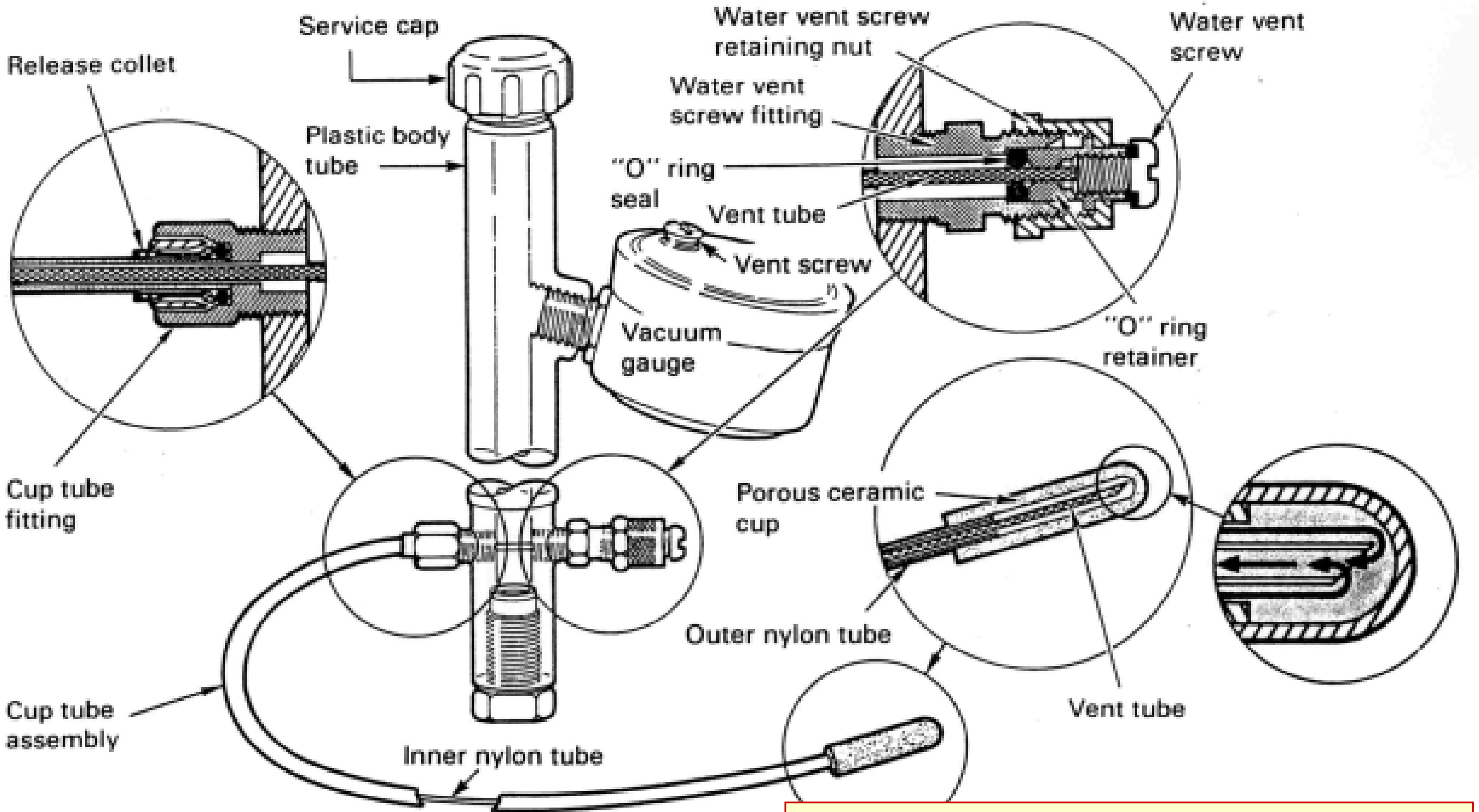
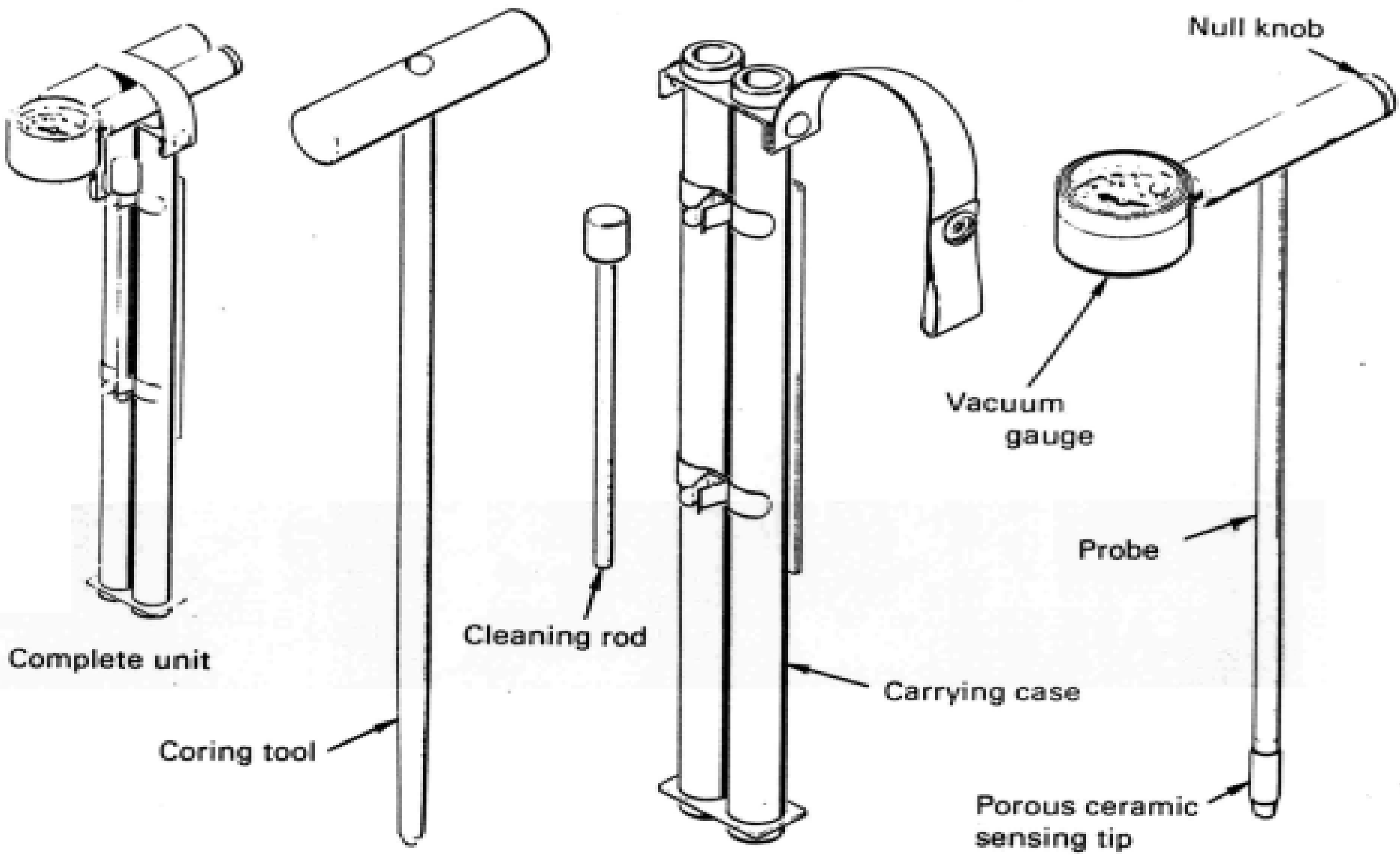


Coaxial tubing for ease in flushing diffused air

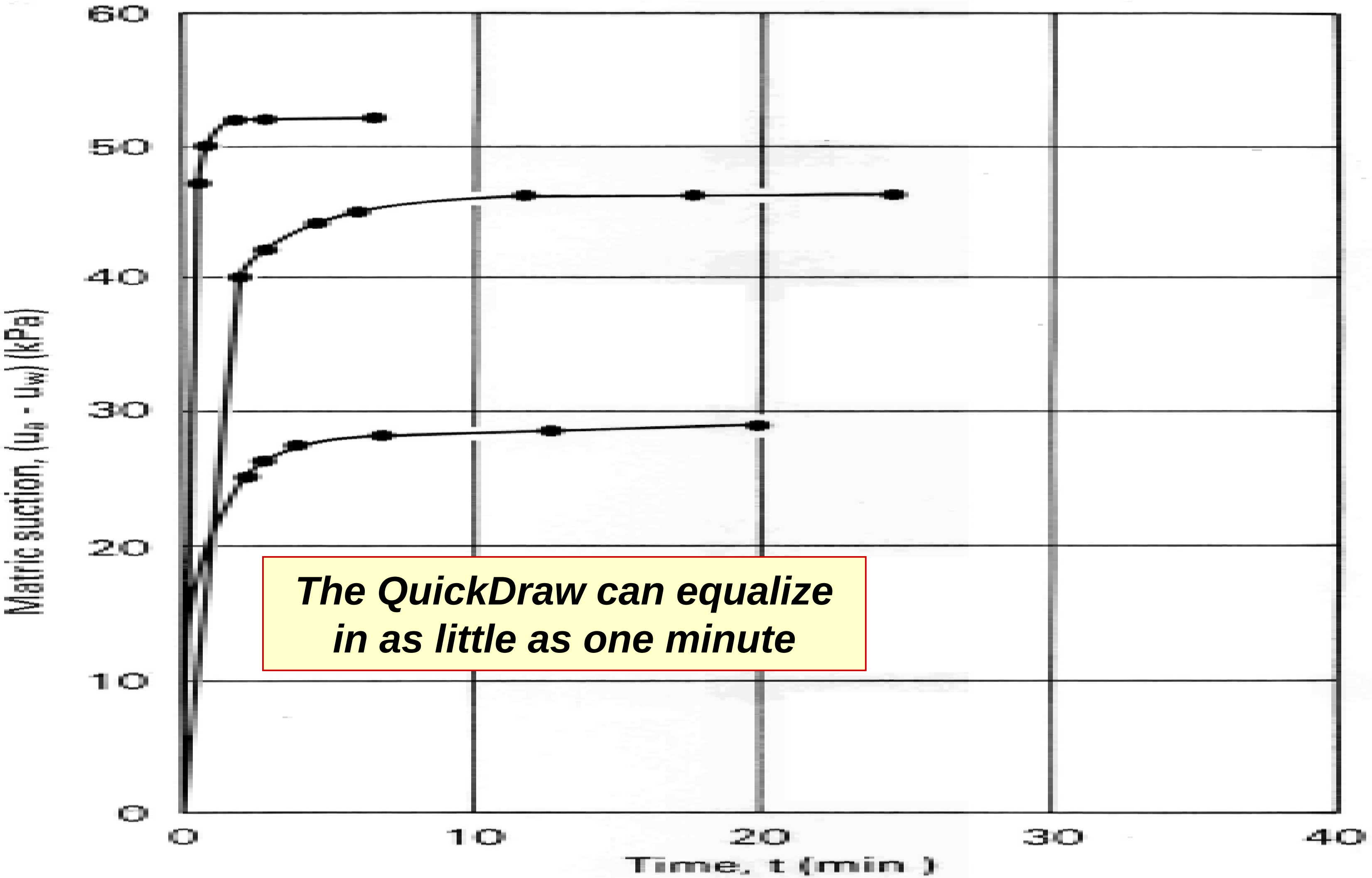
Small tip tensiometer with flexible coaxial tubing (from Soilmoisture Equipment Corporation)

Quick Draw Tensiometer



Quick Draw tensiometer with coring tool and carrying case
(from Soilmoisture Equipment Corporation)

Most valuable tensiometer for geotechnical engineering



Typical responses of Quick Draw tensiometer in decomposed volcanics (from Sweeney, 1982)

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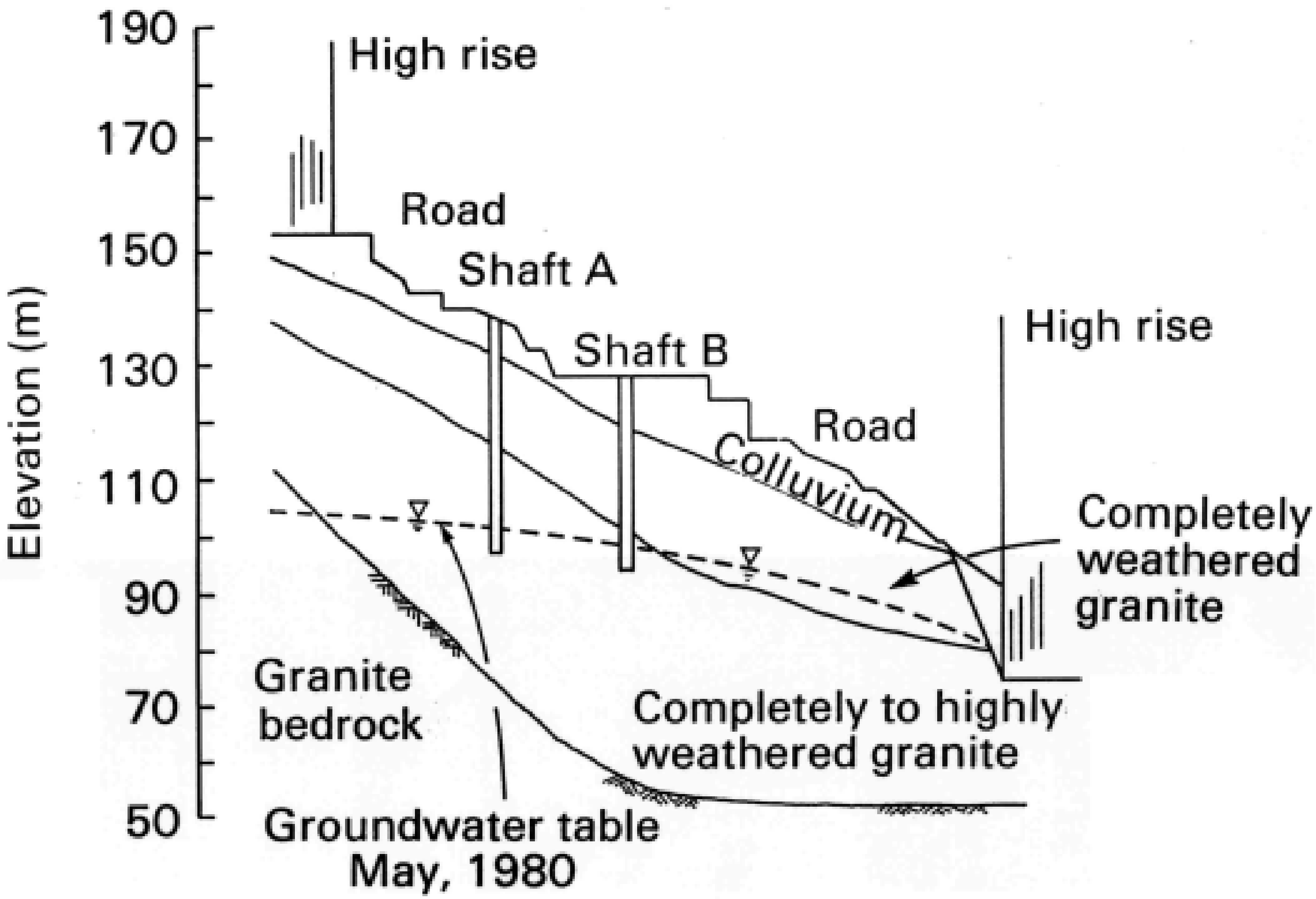
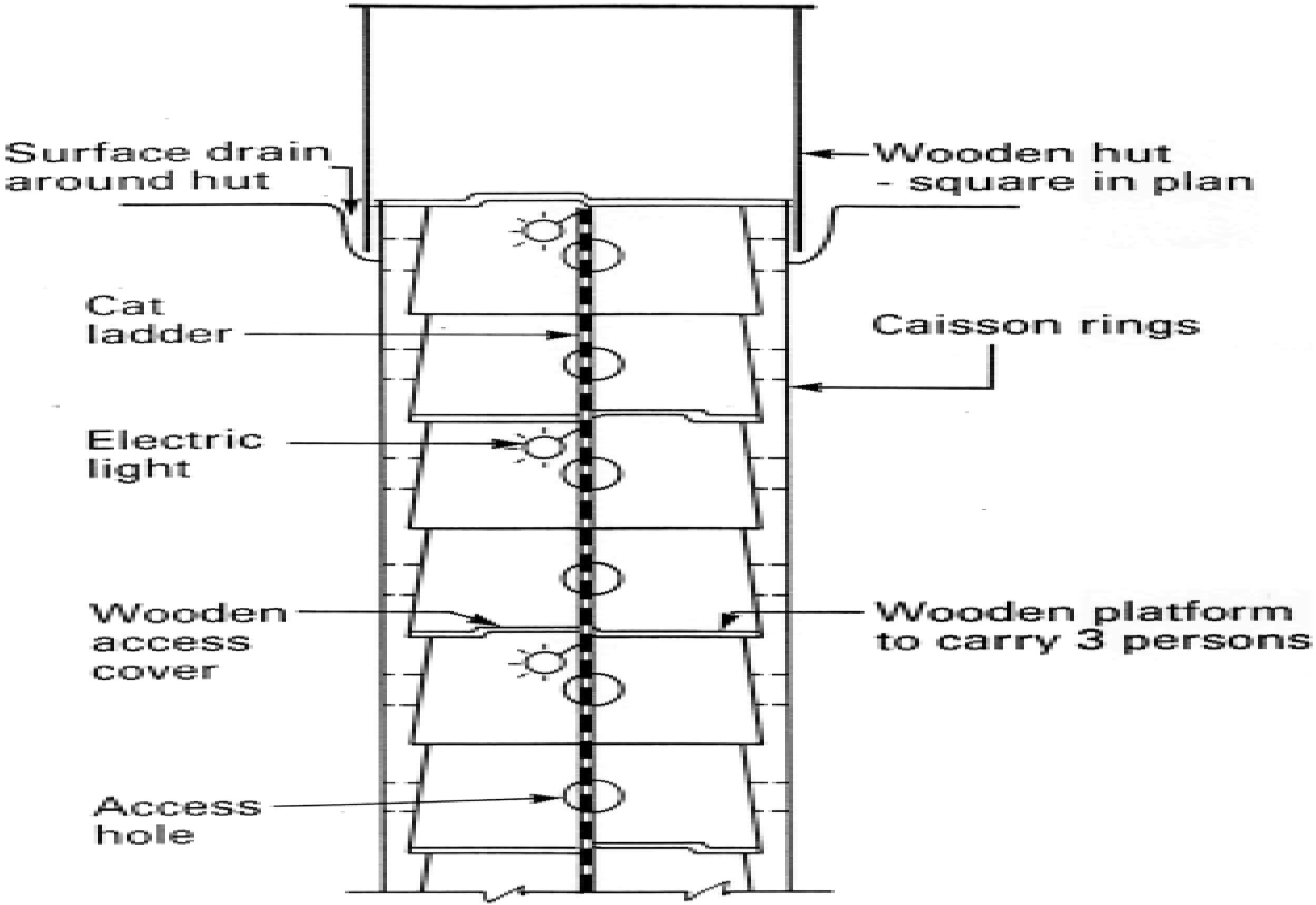
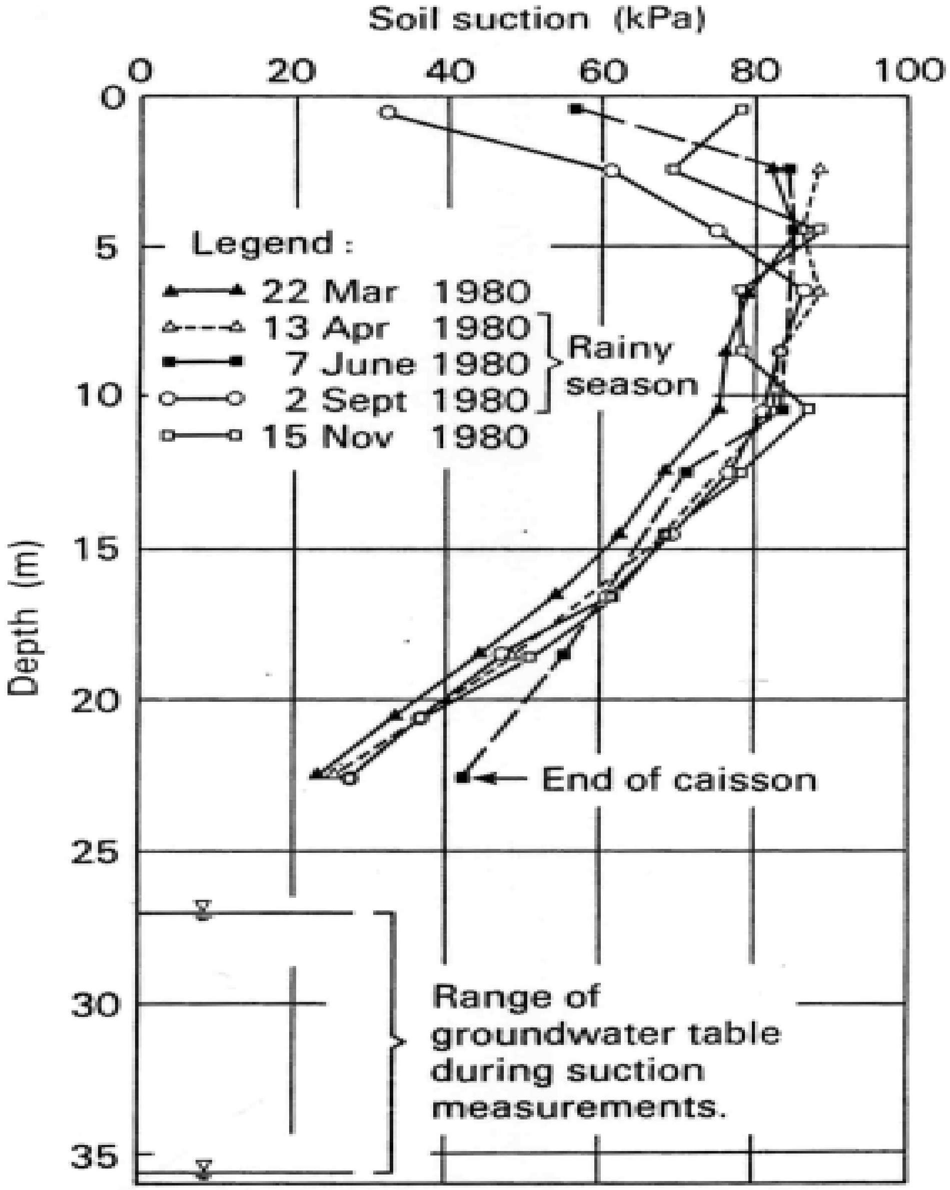


Cut slope of decomposed granite where tensiometers were used to measure negative pore-water pressure (from Sweeney, 1982)



Observation shaft for installing tensiometers in the field
(from Sweeney, 1982)



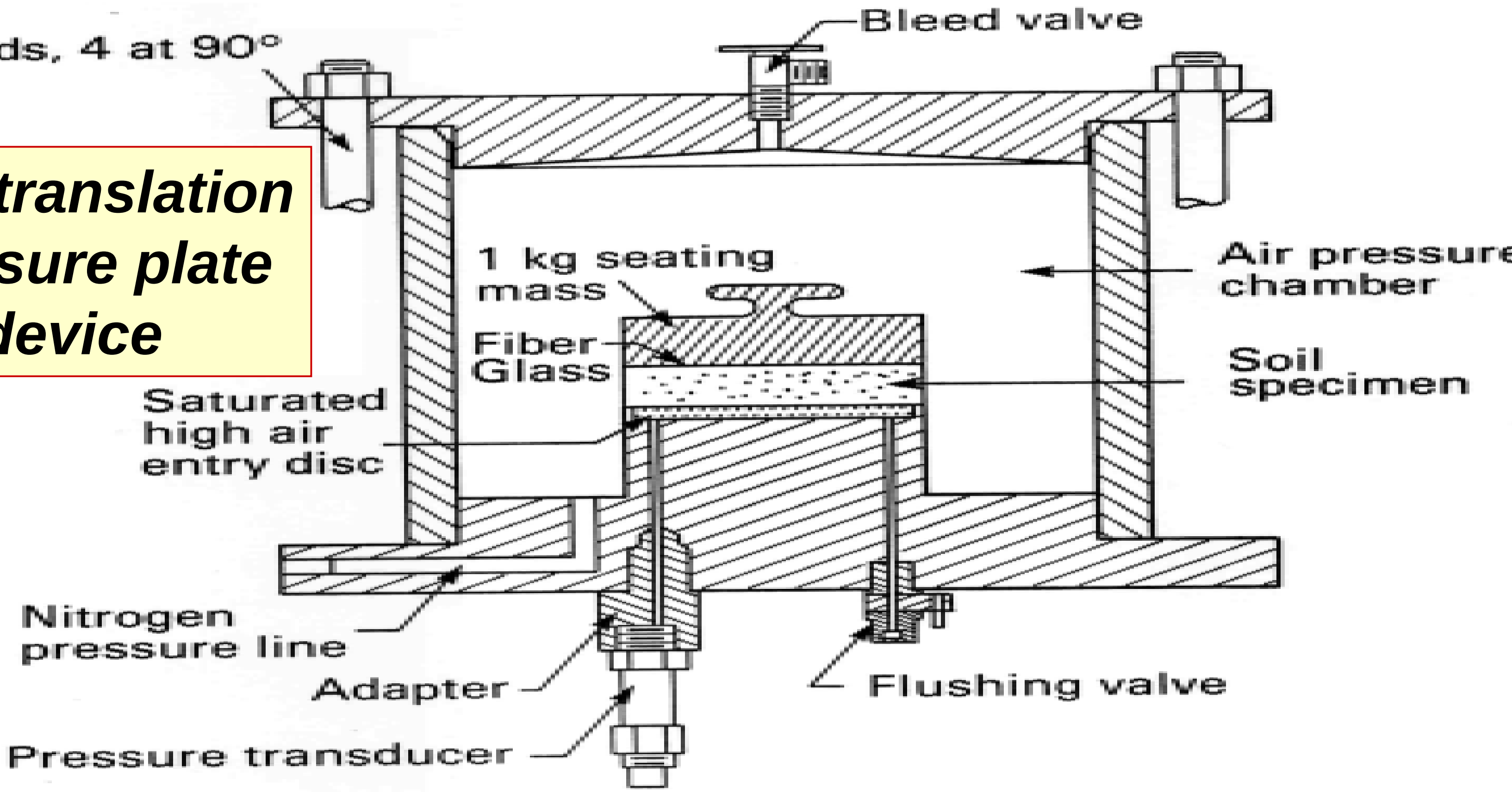
Decomposed Granite

Two distinct mechanisms involved:

1.) Decrease in suction at ground surface

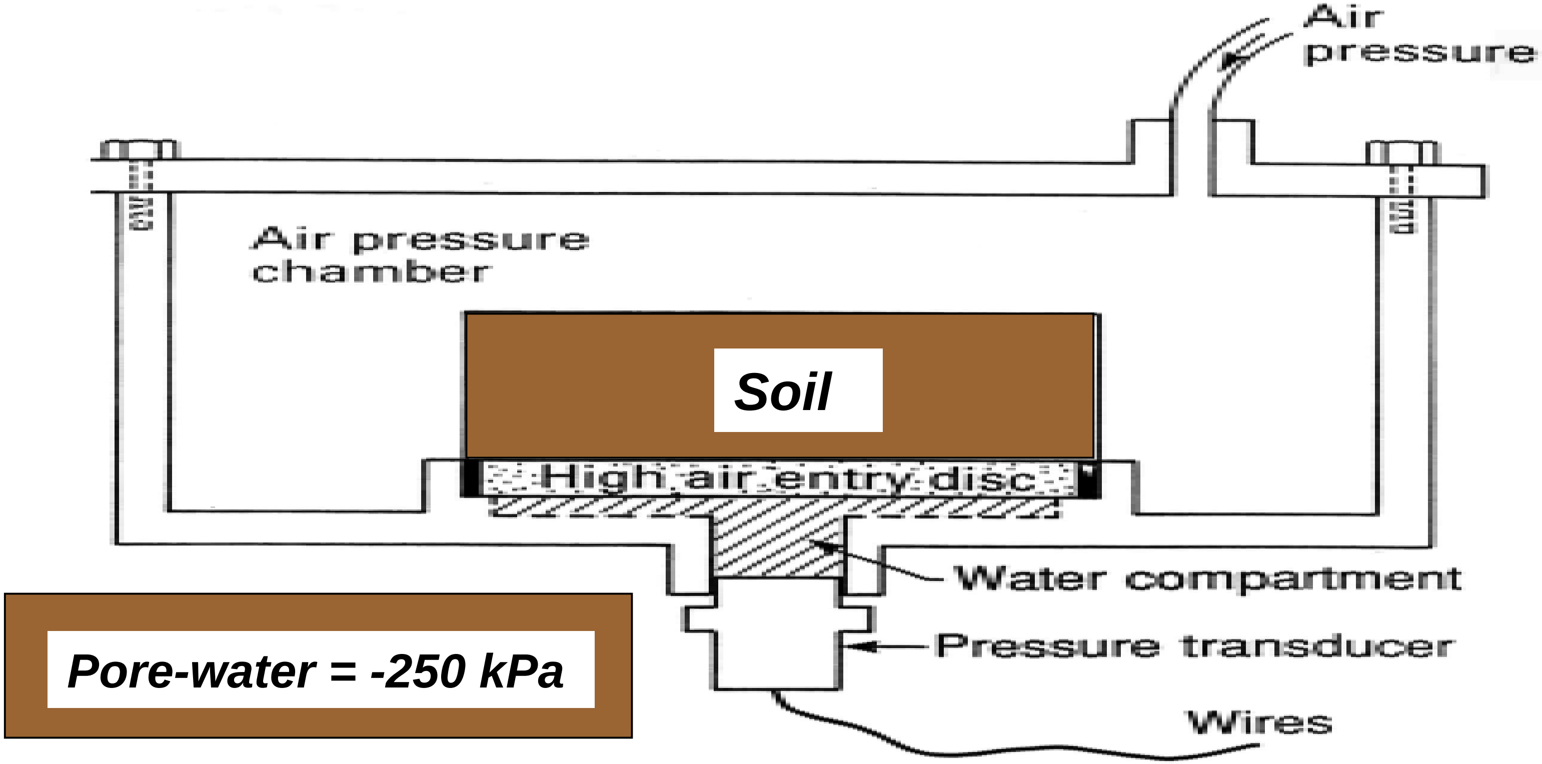
2.) Fluctuation of the groundwater table

Axis-translation pressure plate device



Concept: Translate the Measurement World to Positive Pressures

Pressure plate apparatus for measuring negative pore-water pressures using the axis-translation technique (from Olson and Langfelder, 1965)



Initial stresses

$\sigma = 0$
$u_a = 0$ (atmospheric)
$u_w = -250$ kPa

Stress state

$(\sigma - u_a) = 0$
$(u_a - u_w) = 250$ kPa

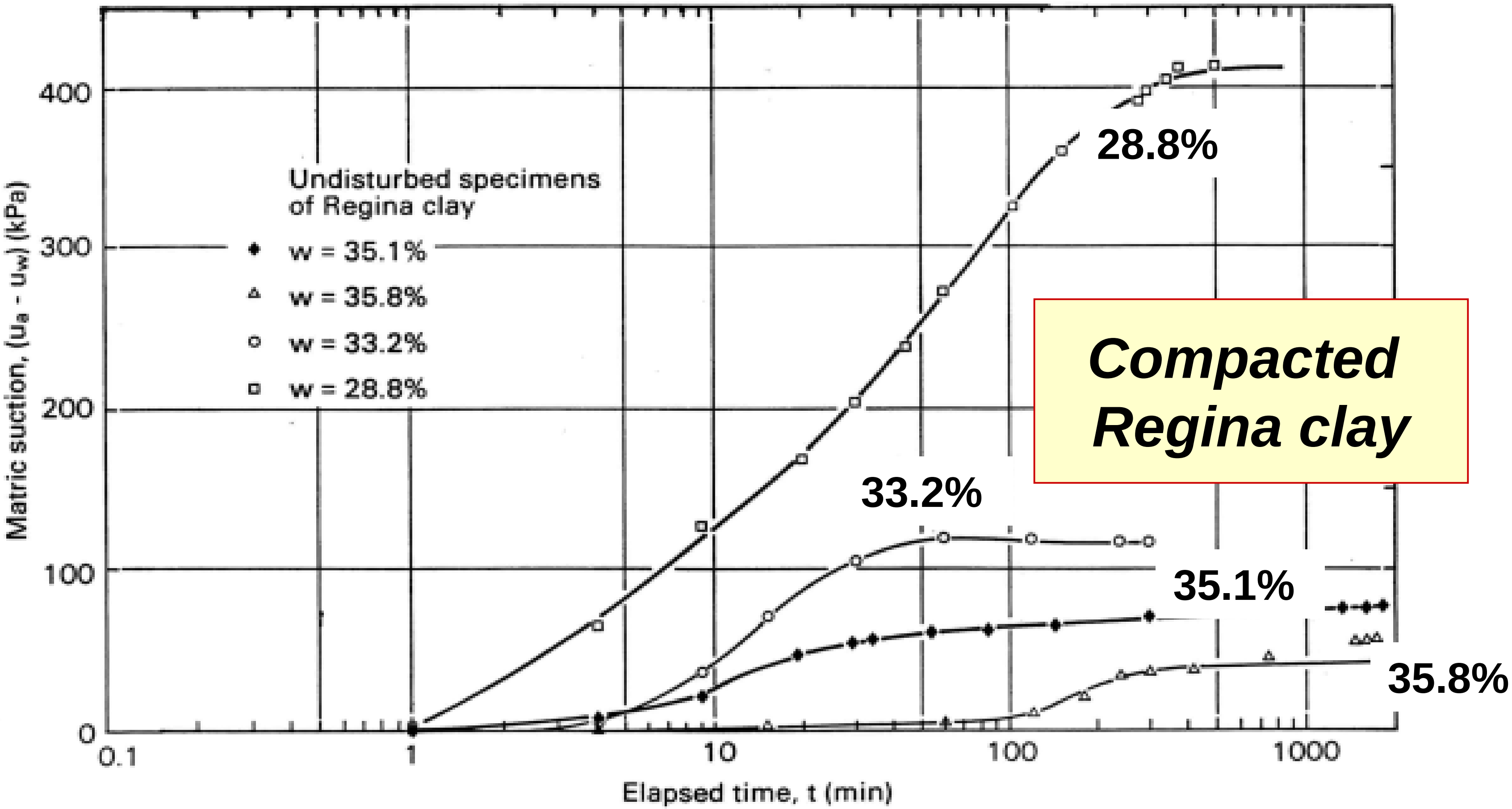
Equilibrium stresses

$\sigma = u_a$
$u_a = 255$ kPa
$u_w = 5$ kPa

Stress state

$(\sigma - u_a) = 0$
$(u_a - u_w) = 250$ kPa

Schematic showing the pressure changes associated with the measurement of matric suction using a null type pressure plate apparatus (from Fredlund, 1989)



Response versus time for matric suction measurements on Regina clay using the axis-translation technique (from Widger, 1976)

Variability in contact results in different response times

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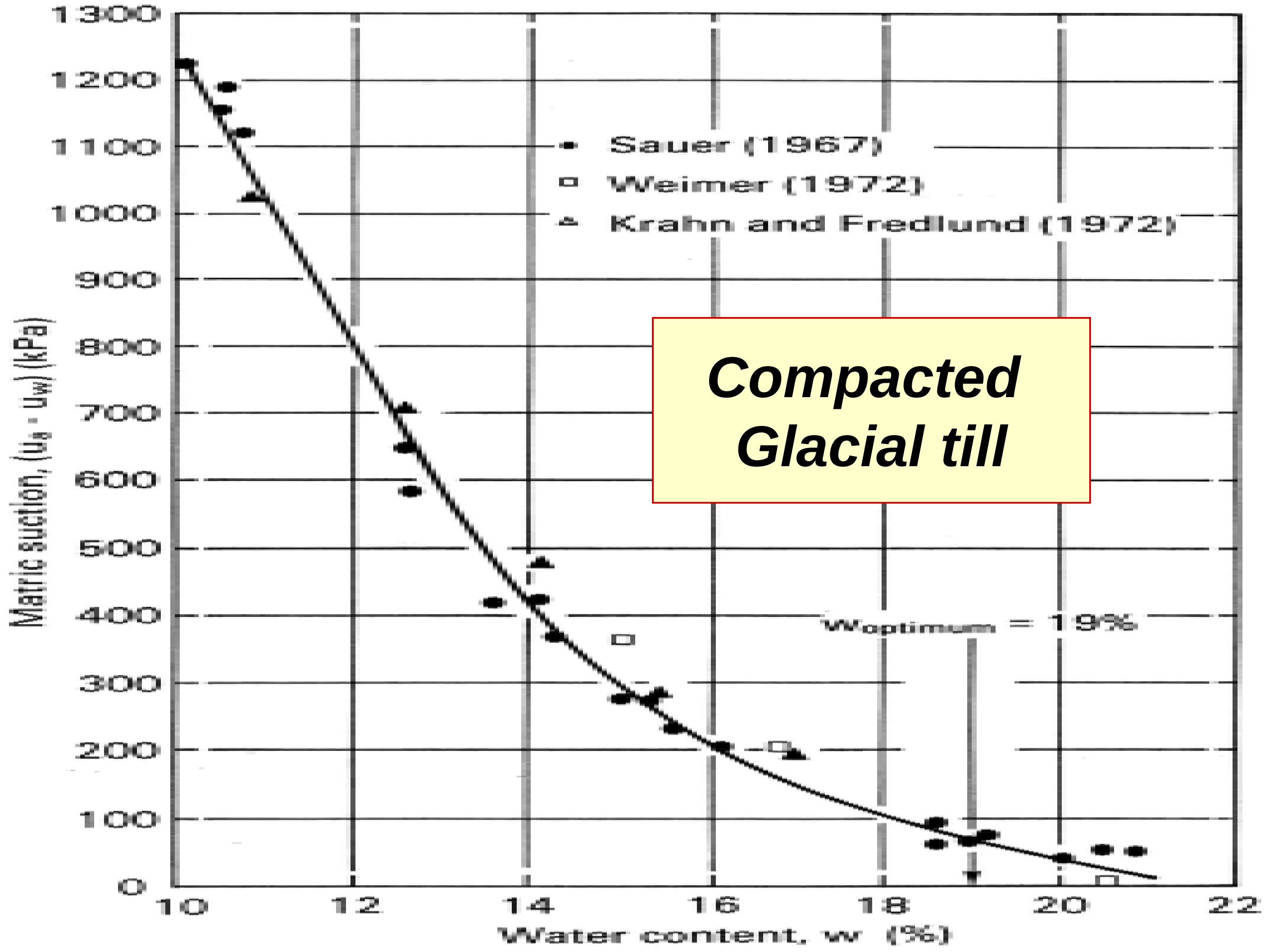
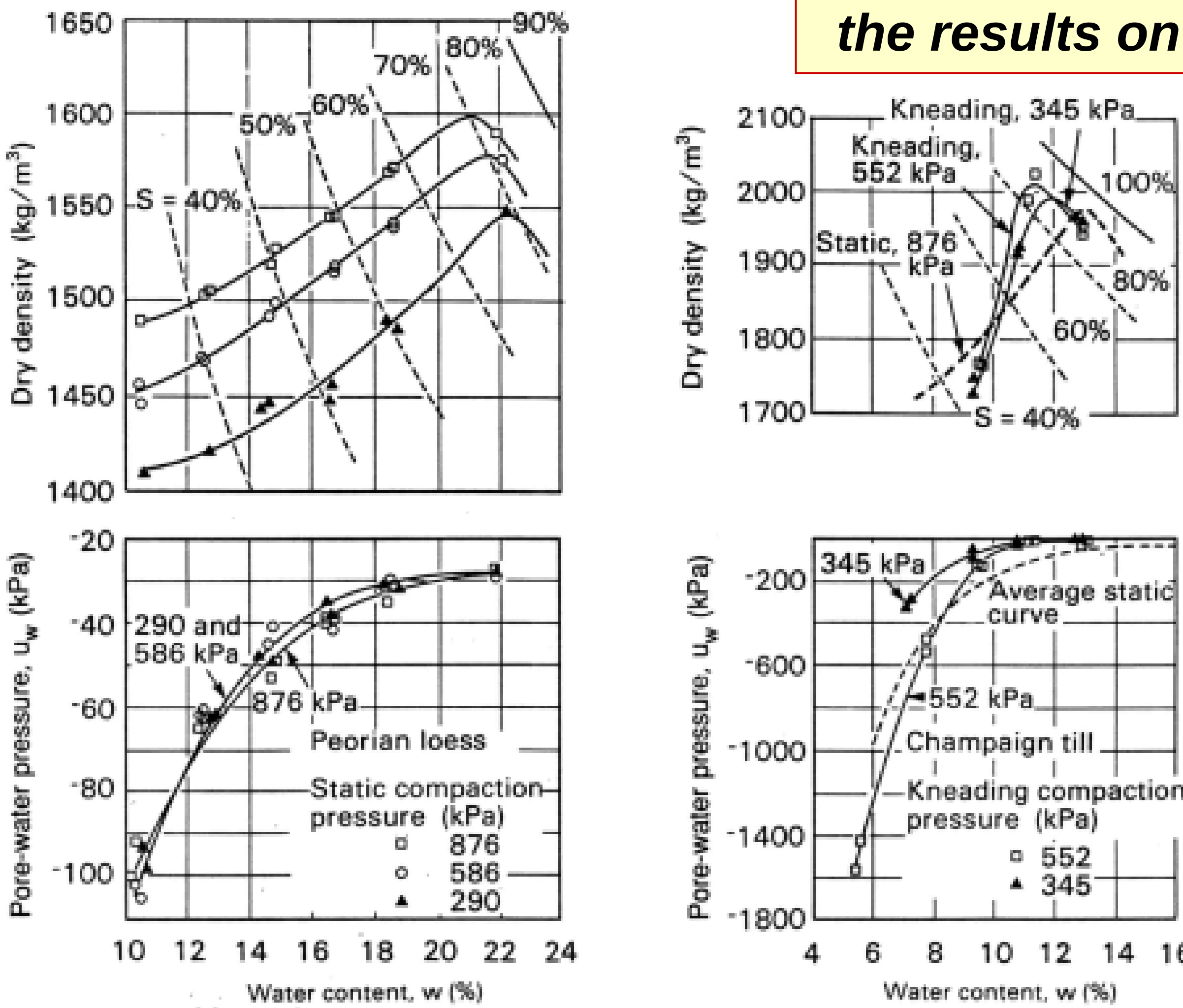


Water content versus matric suction for compacted specimens of glacial till

Note the independence of the results on the density



Negative pore-water pressure measurements on compacted specimens using the axis-translation technique (from Olson and Langfelder, 1965)

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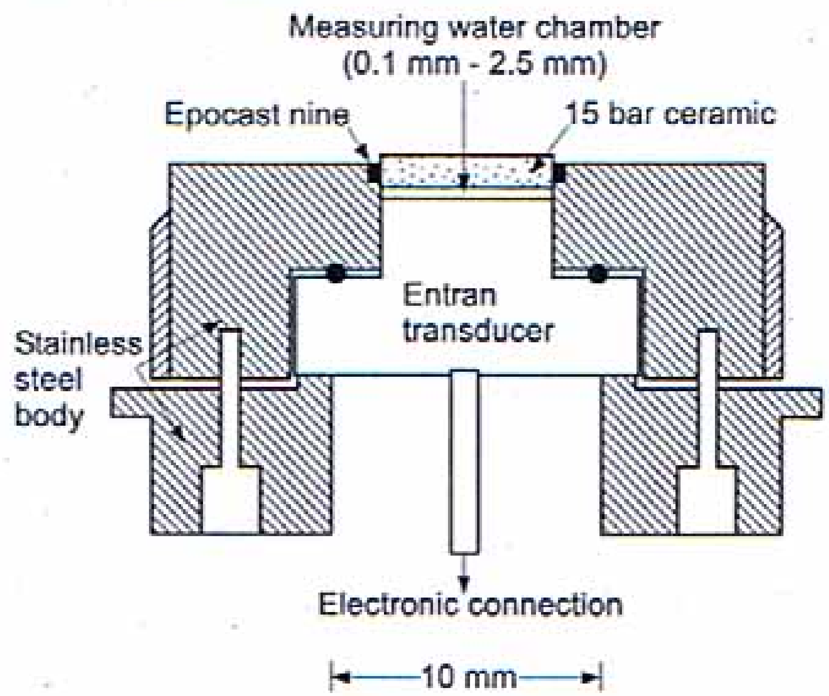
Direct Measurement of High Soil Suction

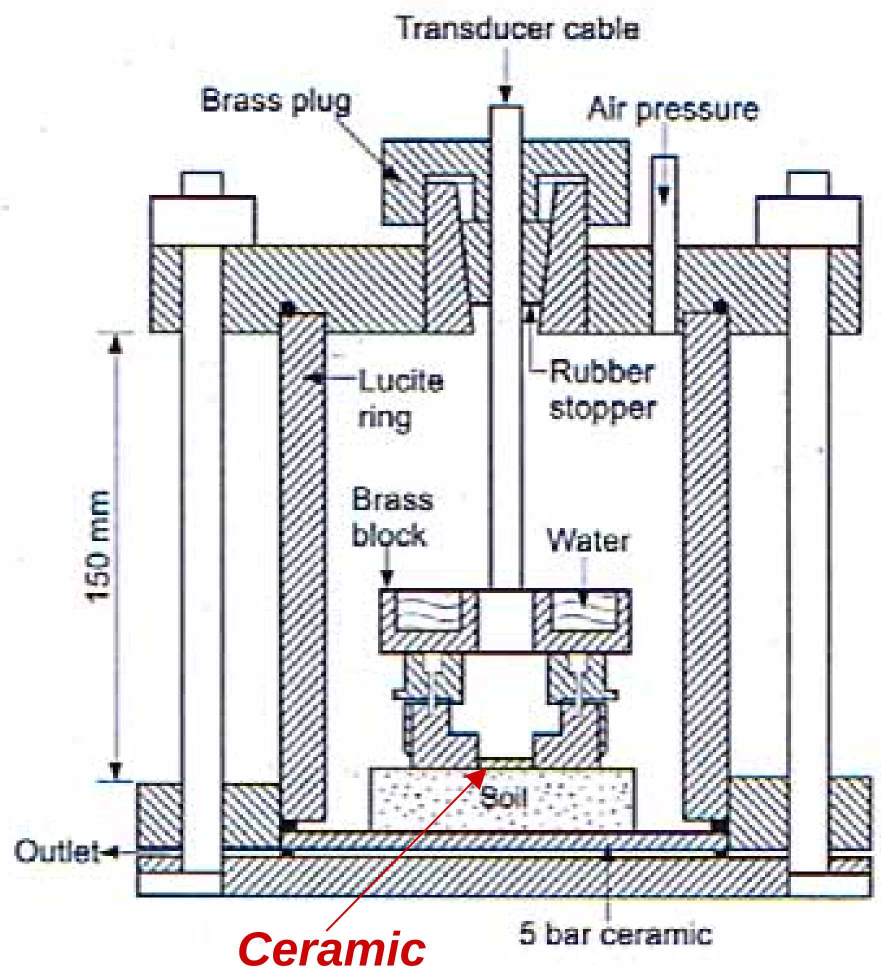
- *Guan, Y. and Fredlund, D.G. Fredlund, (1997). "Direct Measurement of High Soil Suction", Proc. 3rd Brazilian Symposium on Unsaturated Soils, Rio de Janeiro, April 21-25, Vol. 2.*
- *Guan, Y. (1996), "The Measurement of Soil Suction", Ph.D. thesis, University of Saskatchewan, Saskatoon, SK., Canada.*
- *Ridley, A. (1993), "The Measurement of Soil Moisture Suction", Ph.D. thesis, Imperial College, London, U.K.*

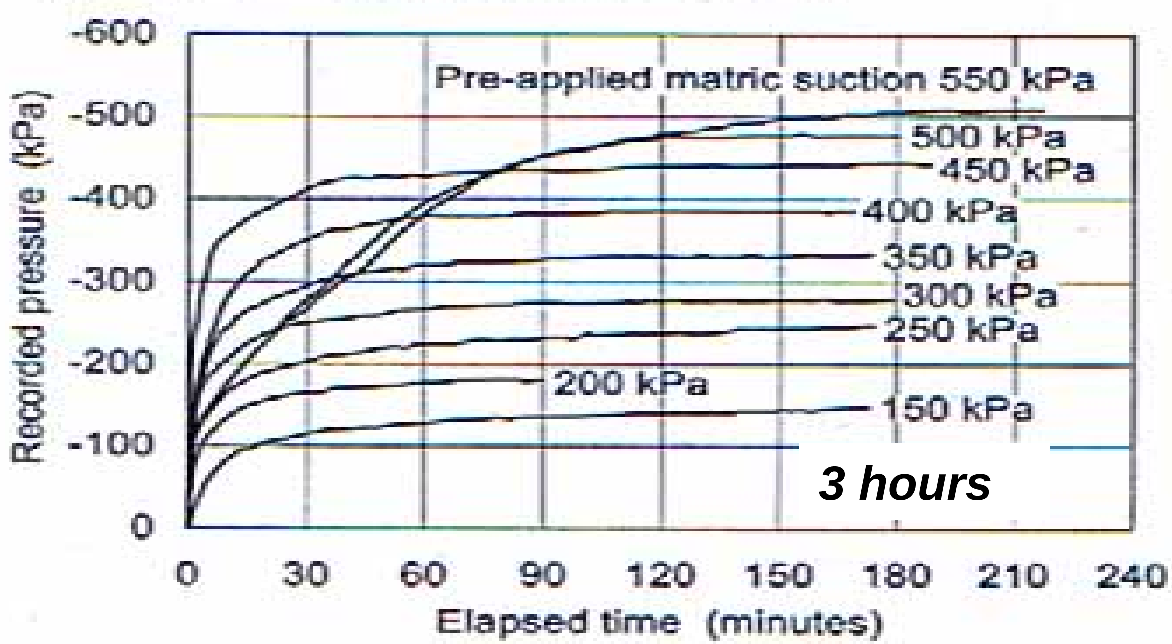
Probe prepared using 6 cycles of pressure from +12,000 kPa to -85 kPa

Modified Pressure Plate for testing the High Suction Probe

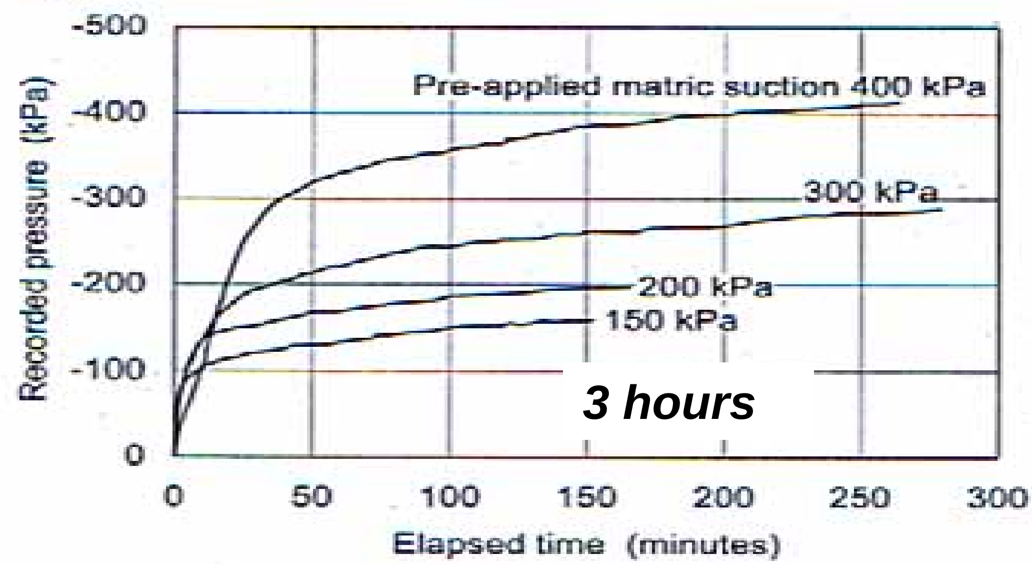


Design of the High Suction Probe





Matric suction measurements on clay



Matric suction measurements on silt

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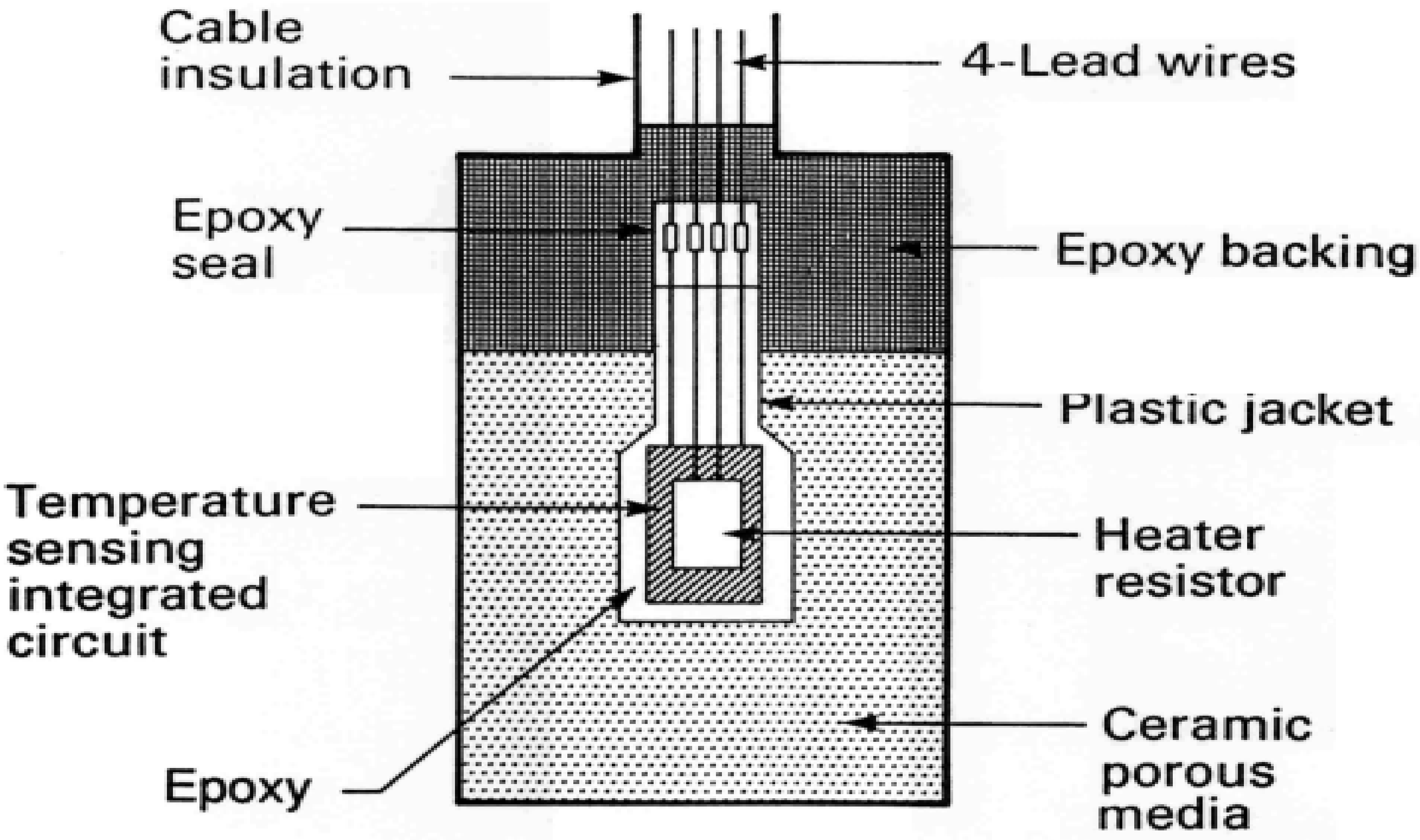
Indirect Measurements of Matric Suction

- *All indirect measurements of matric suction require a special type of ceramic tip*
- *The ceramic must have a wide range of pore sizes*
- *The sensors will have hysteresis and must be calibrated against matric suction*

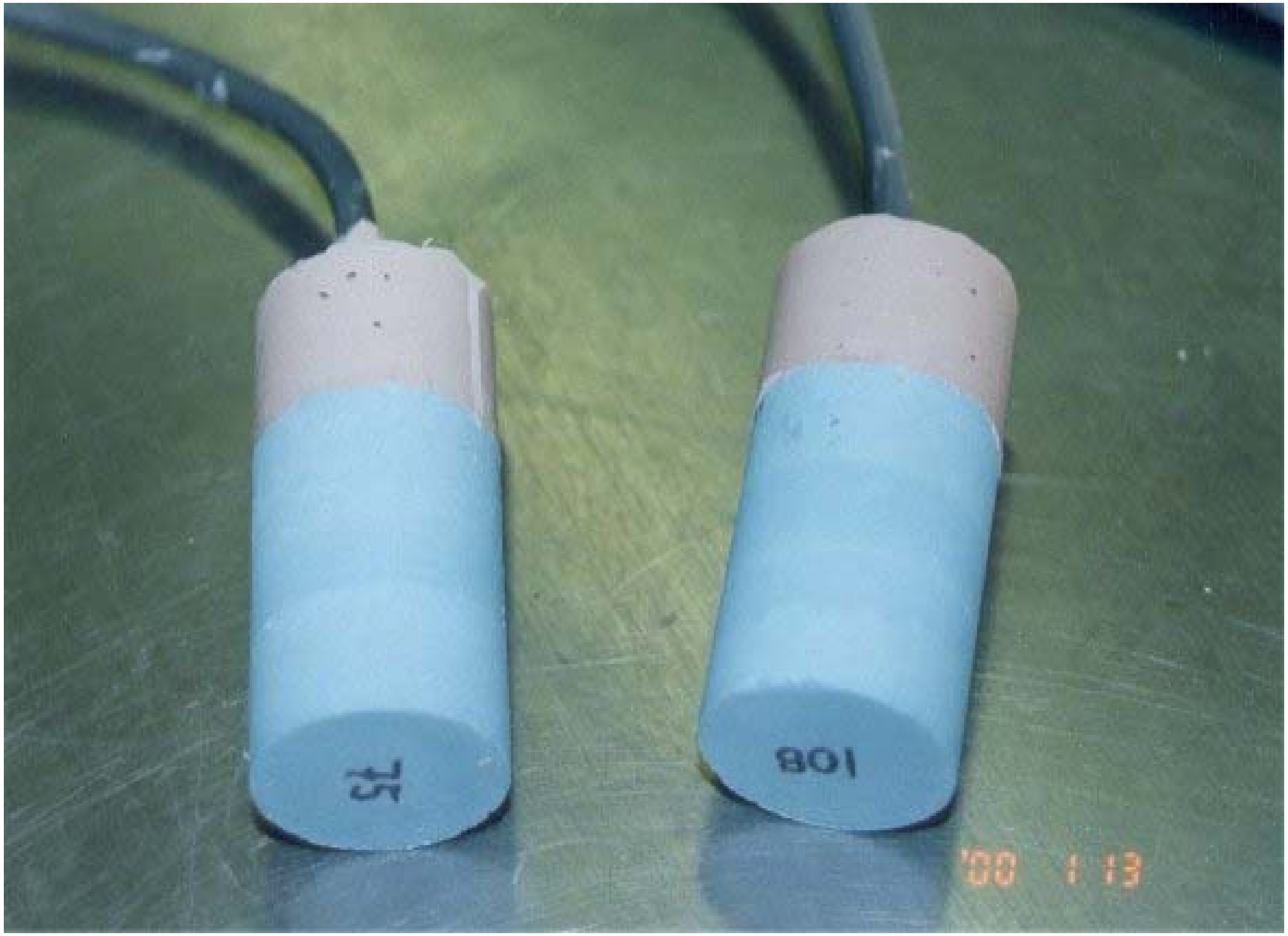
Techniques to Measure Matric Suction

1. Thermal conductivity
2. Resistivity
3. Dielectric constant, TDR, Time Domain Reflectometry



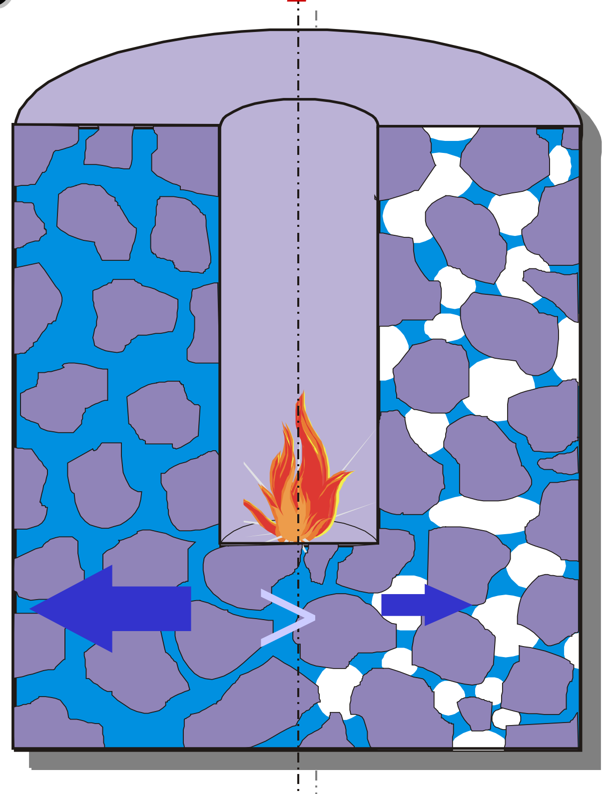
Cross-section of an AGWA-II Thermal Conductivity matric suction sensor

Thermal Conductivity Matric Suction Sensors



Comparison of a Dry and Wet Soil

Thermal conductivity = f { **Water content of ceramic** }



Wet soil near to saturation

Dry soil at 50% saturation

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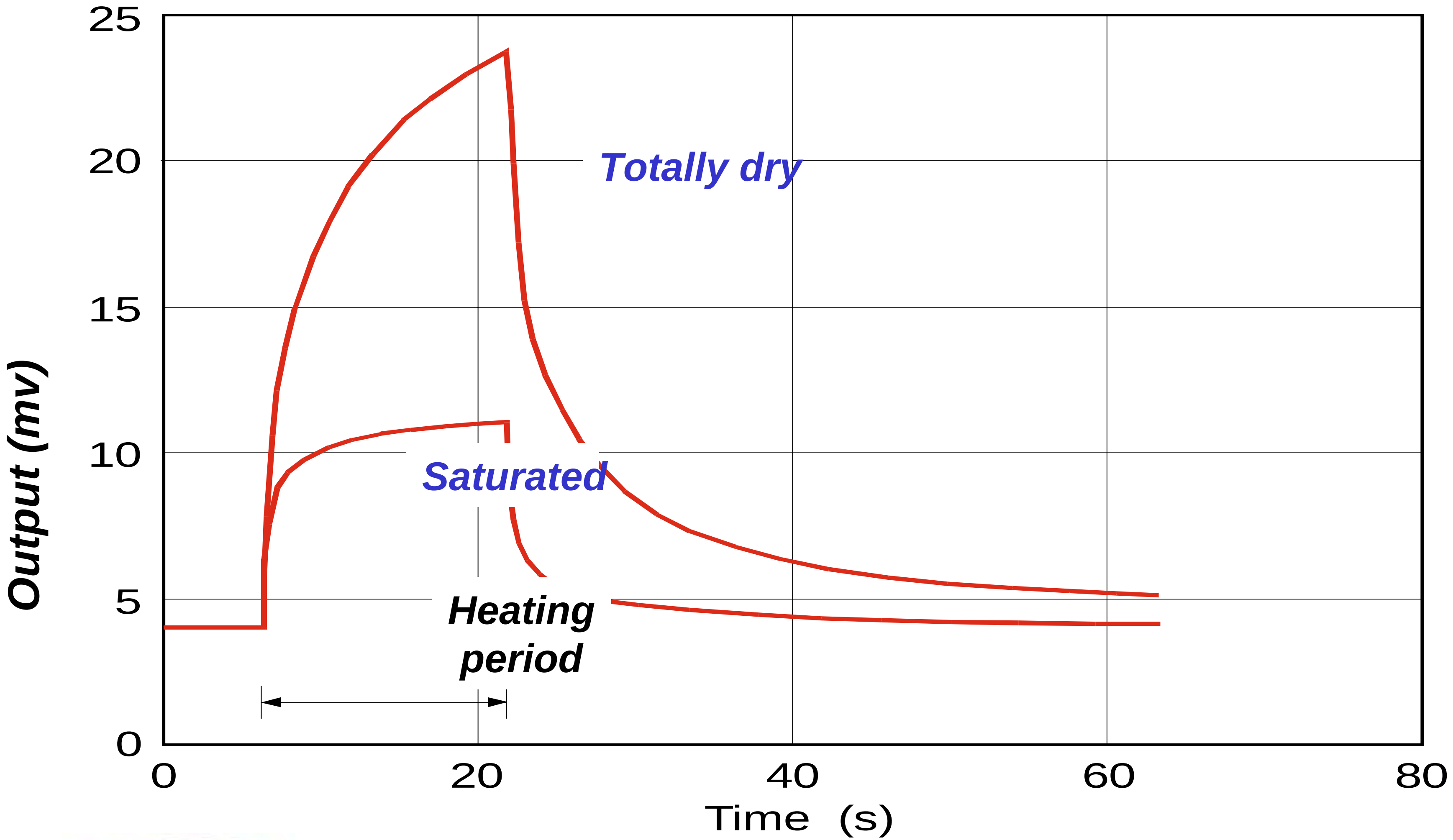
Typical Heating Curves for a Thermal Conductivity Sensor



Final Calibration Setup

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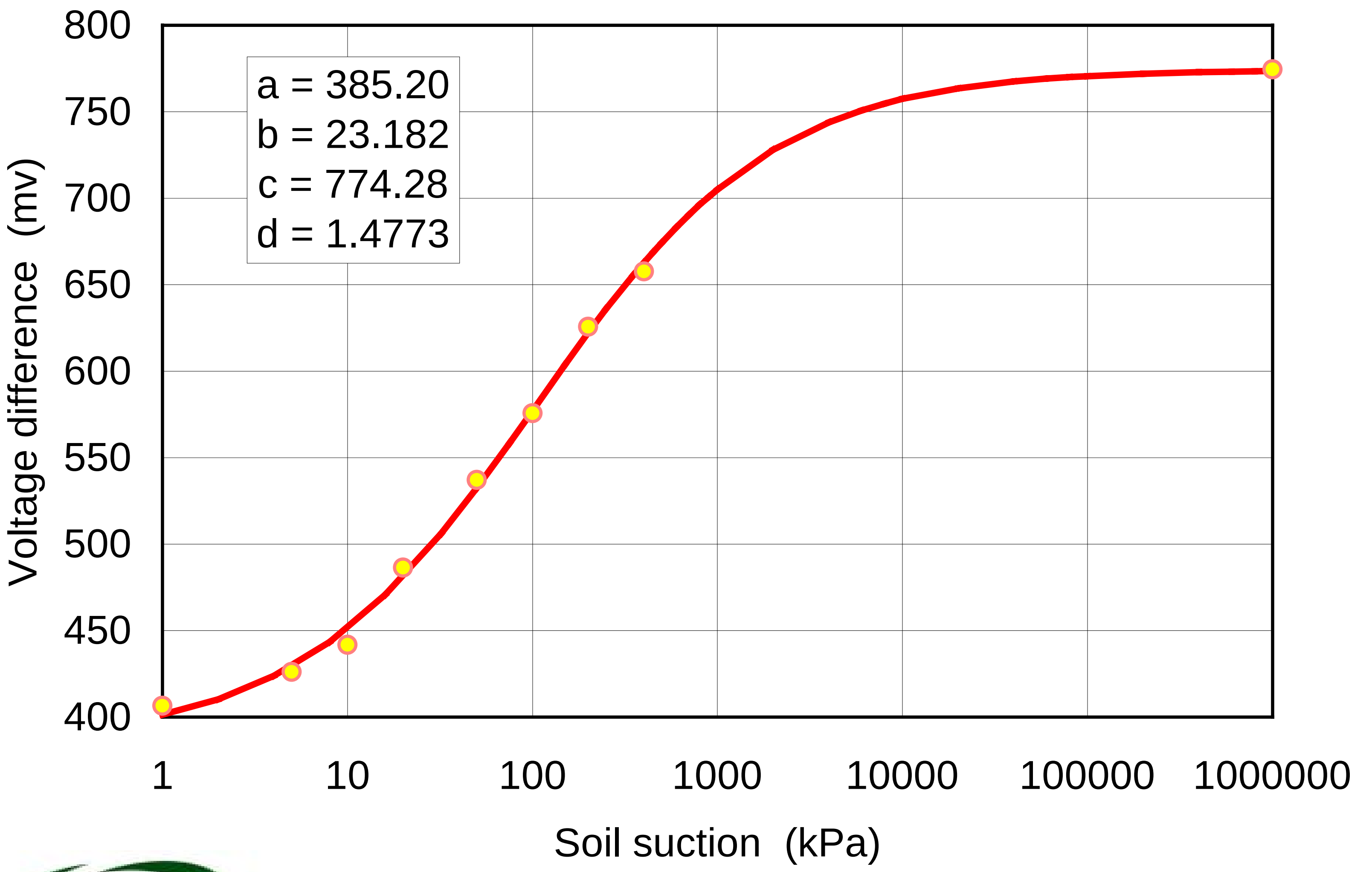
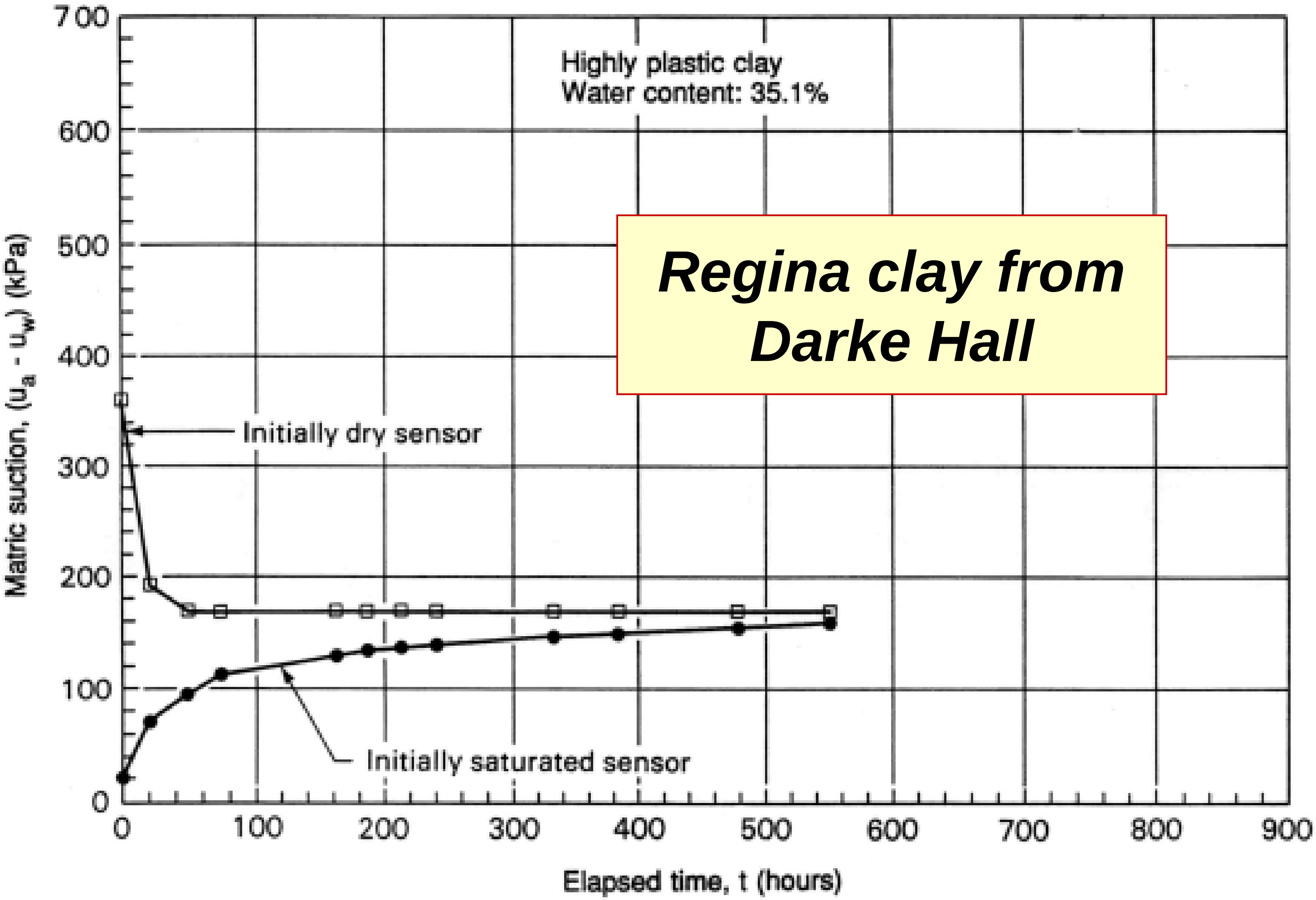
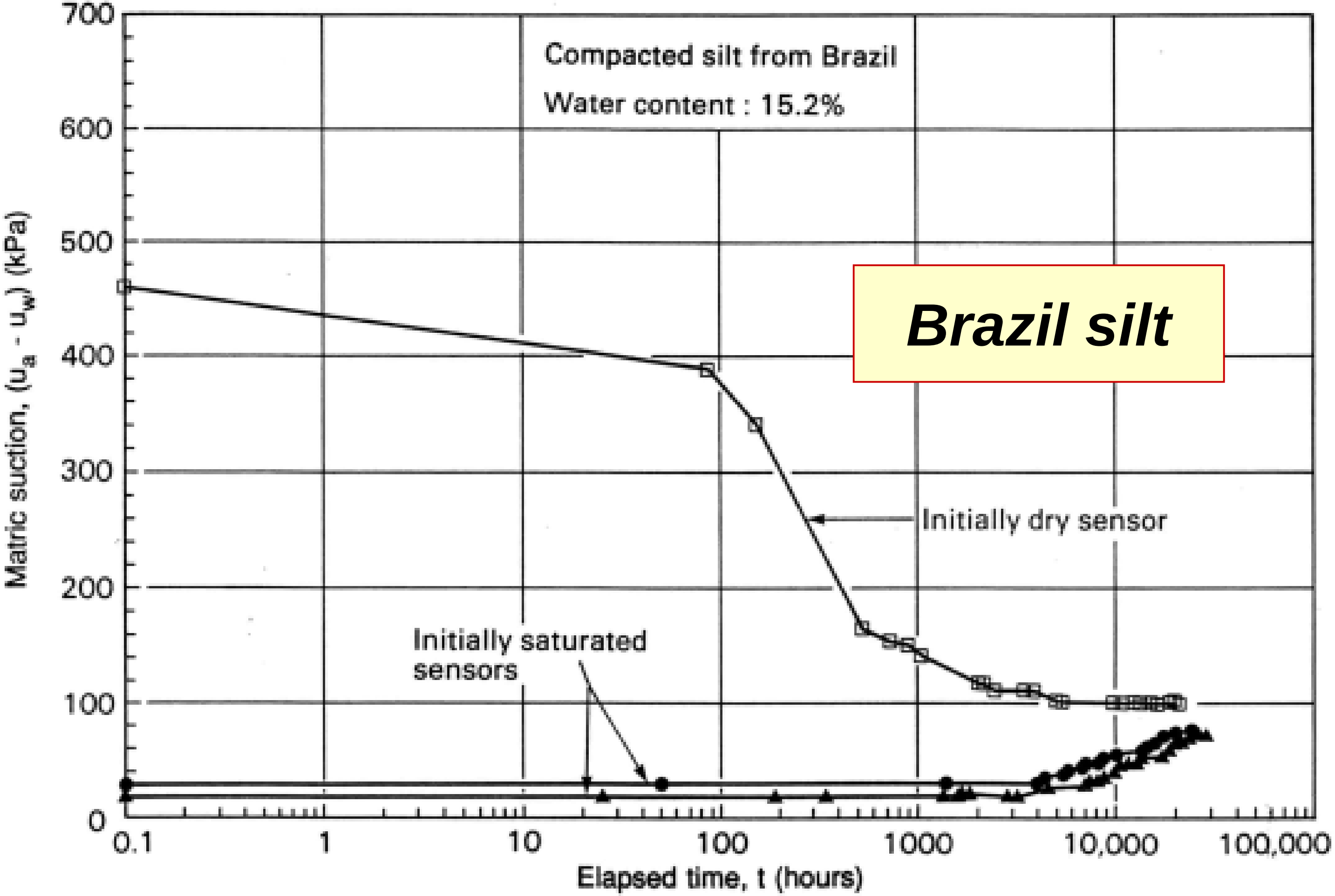
Typical Calibration Curve



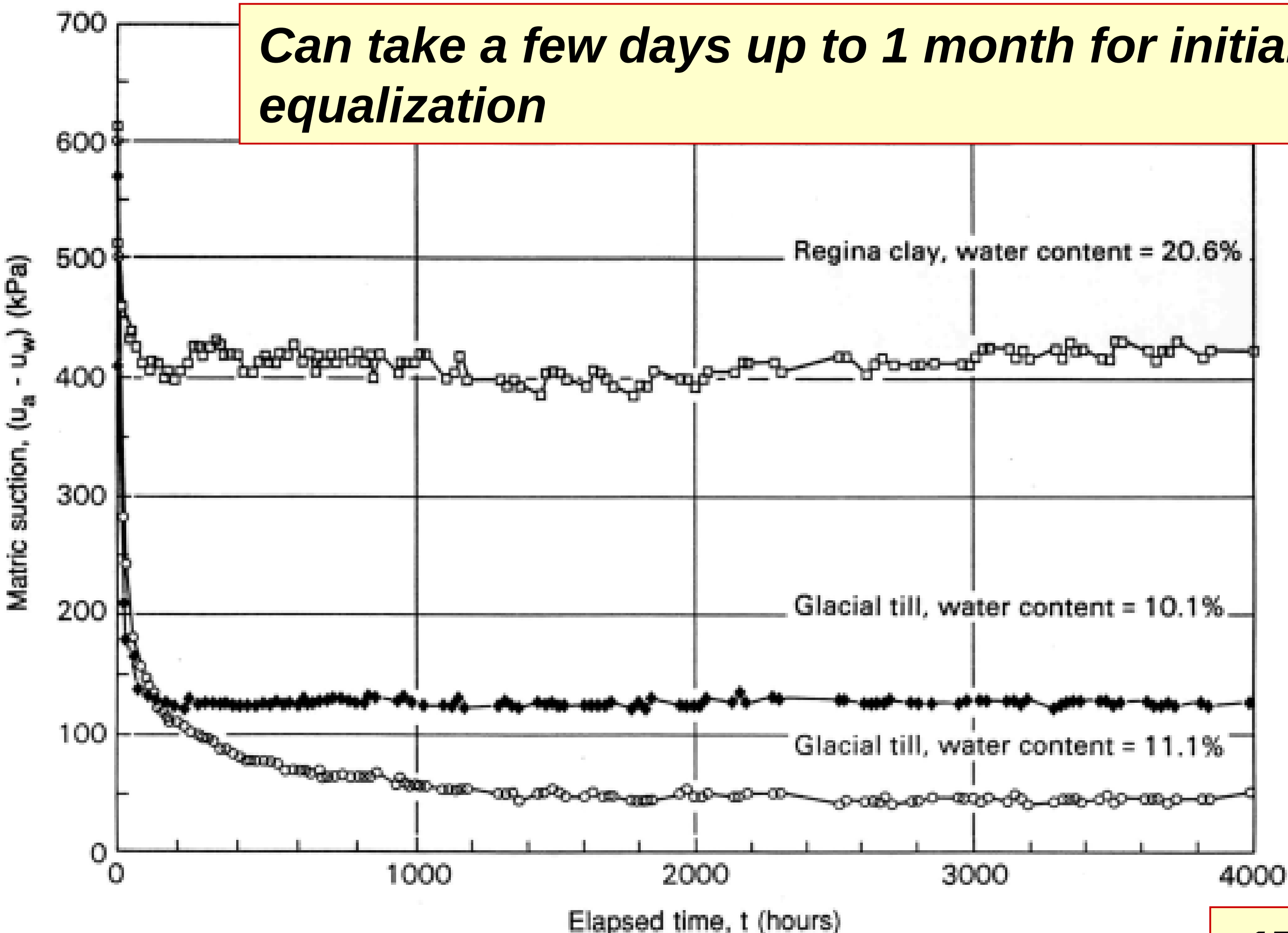


Laboratory measurements of matric suction on highly plastic clay from Darke Hall, Regina, Saskatchewan, Canada (w = 35.1%)



Laboratory measurements of matric suctions on compacted silt from Brazil (w = 15.2%)

Can take a few days up to 1 month for initial equalization



170 days

Field measurements of matric suction using the AGWA-II thermal conductivity sensors under a controlled environment (Testtrack facility, Department of Highways, Regina, Canada)

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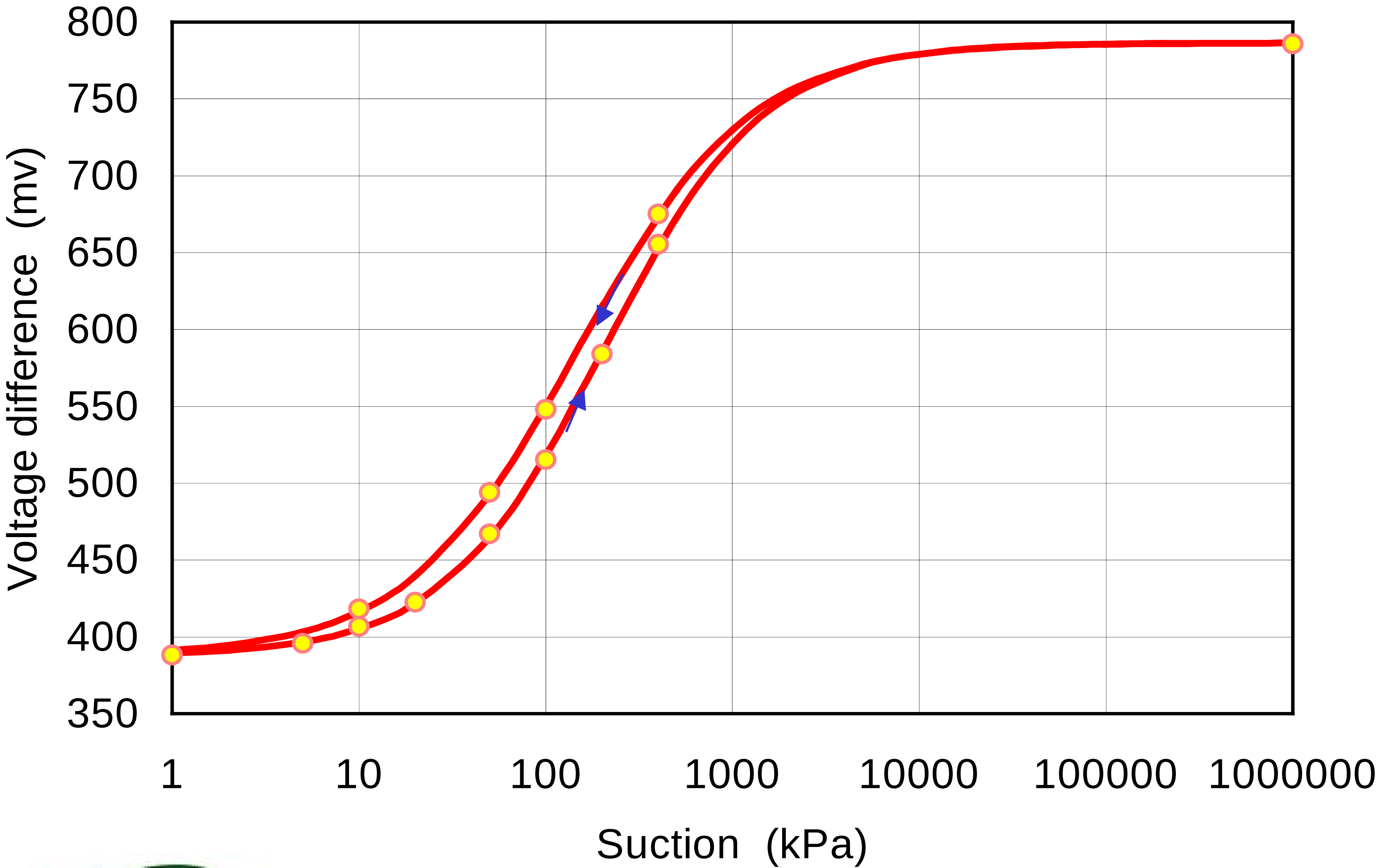
Sensor Response Resulting from Hysteresis in Ceramic



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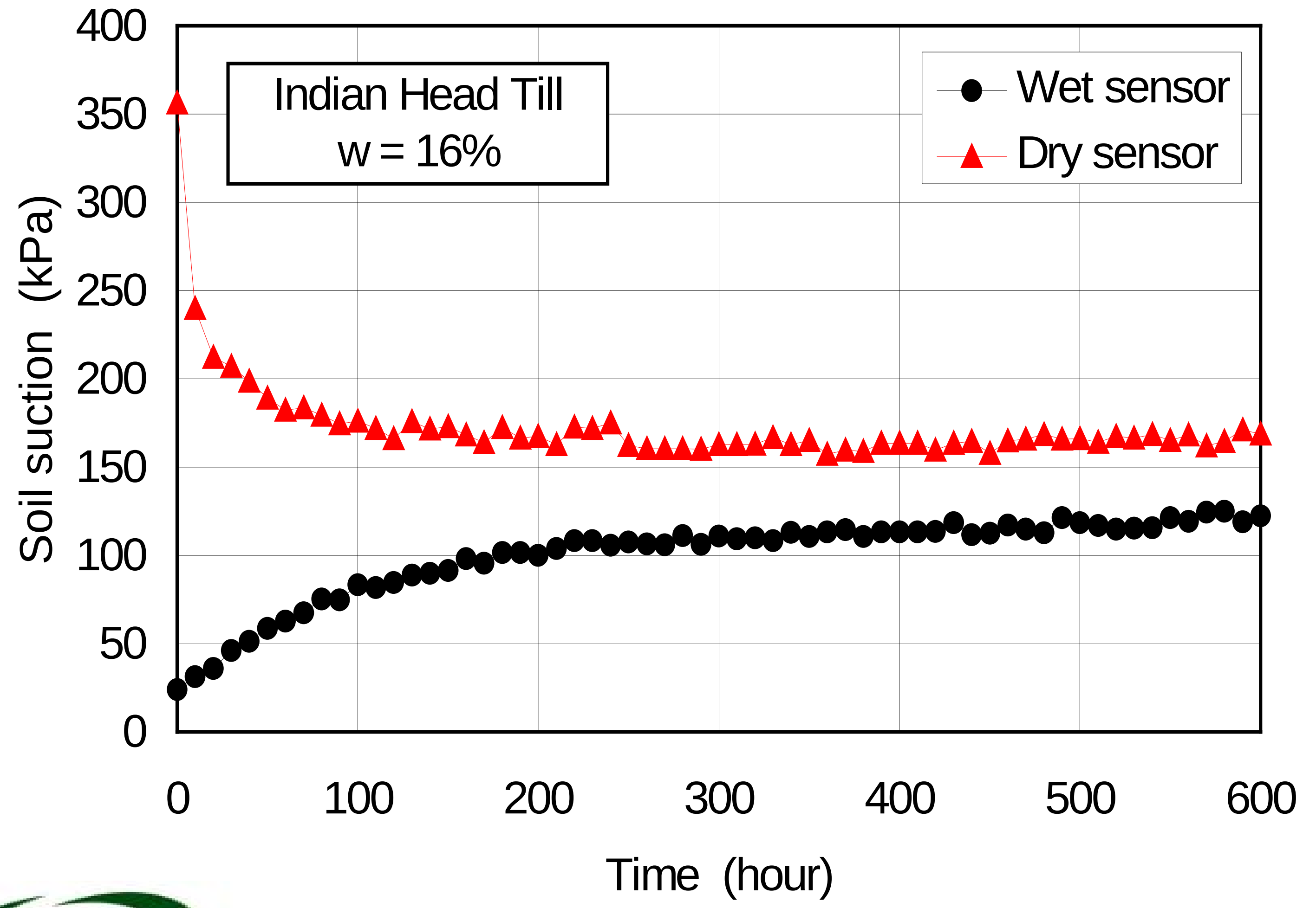
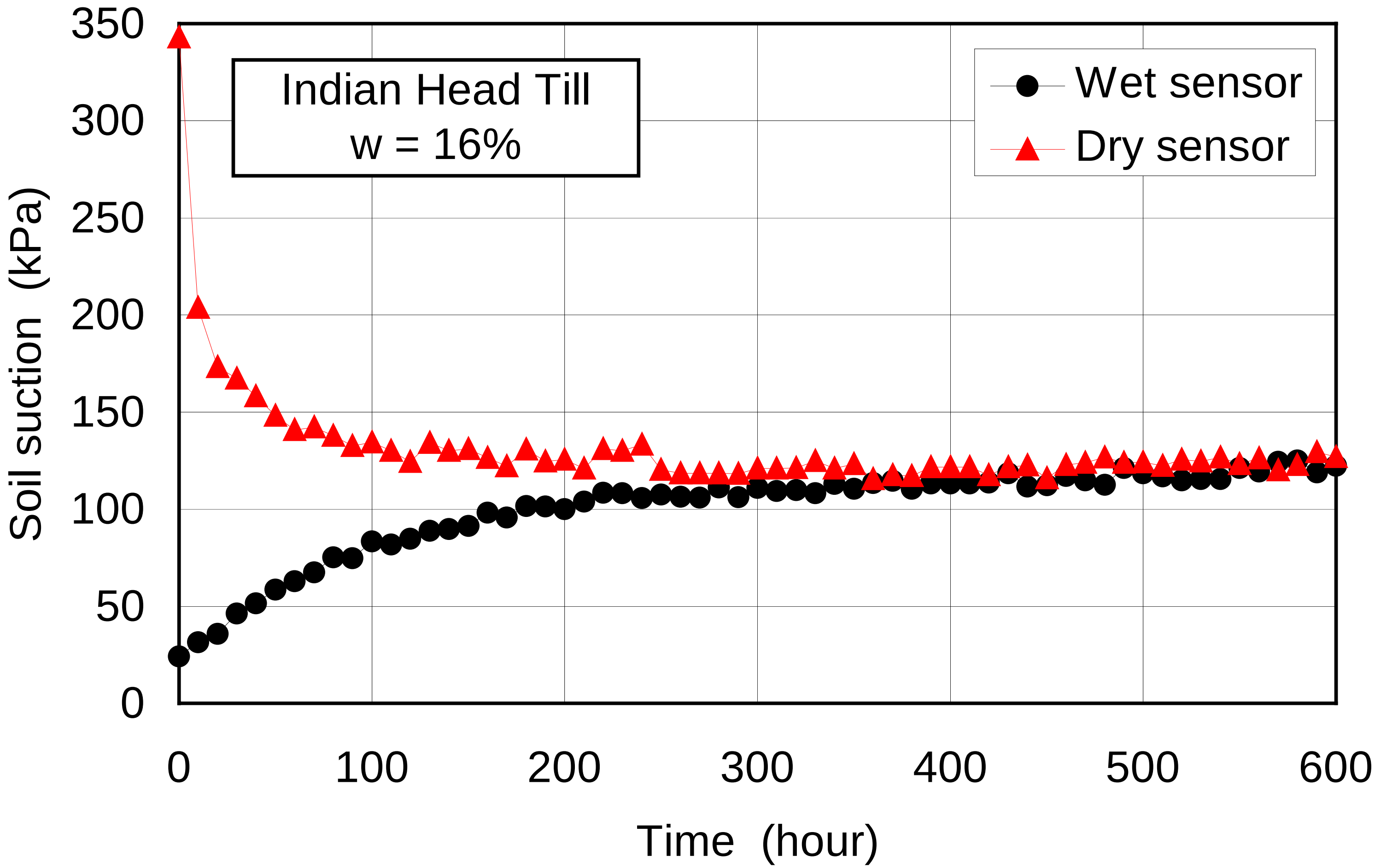
Suction Measured Without Considering Hysteresis



Suction Measured When Considering Hysteresis



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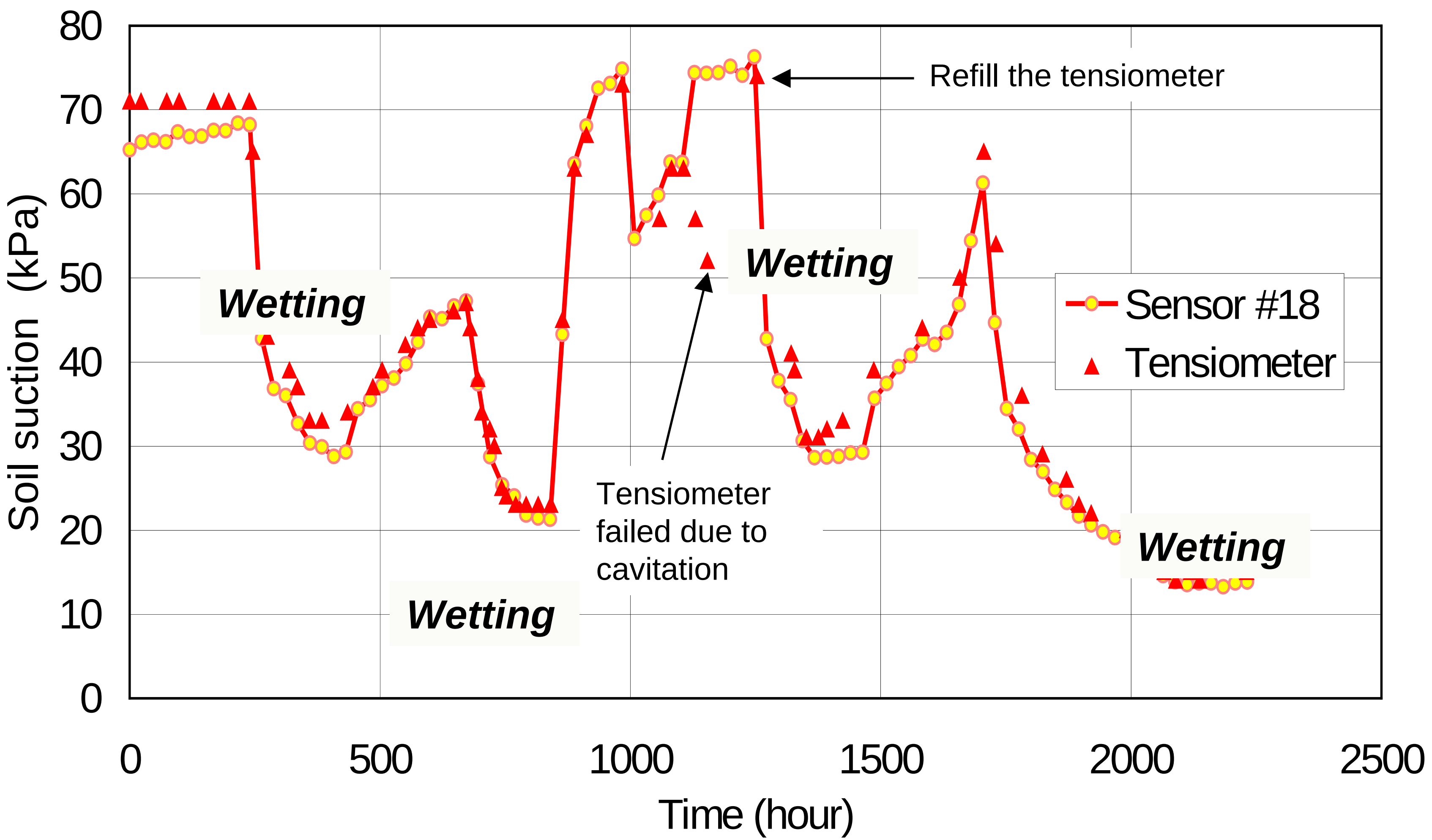
Laboratory Soil Suction Measurements



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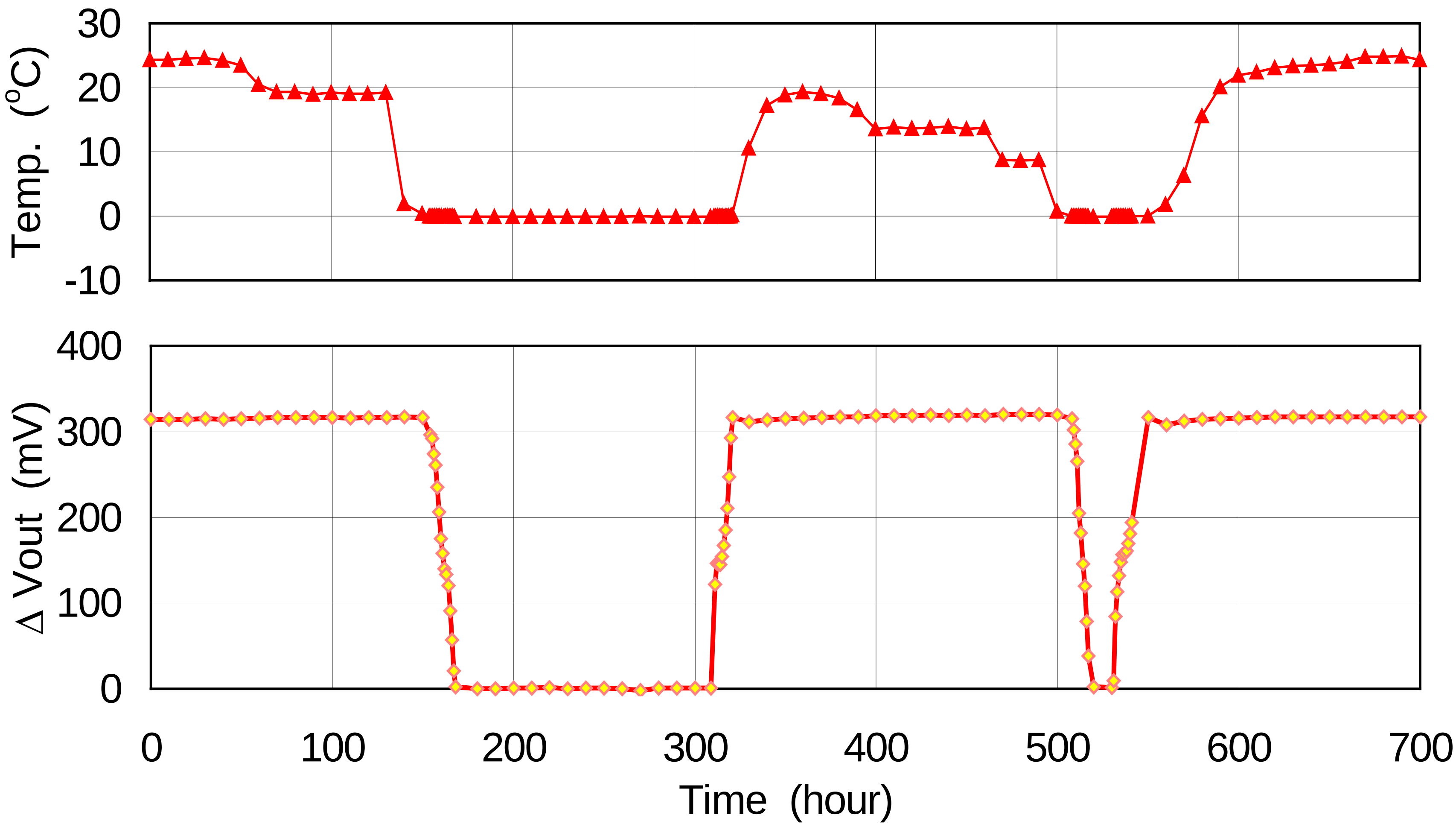
Influence of Freeze-Thaw Cycles (soil suction = 50 kPa)



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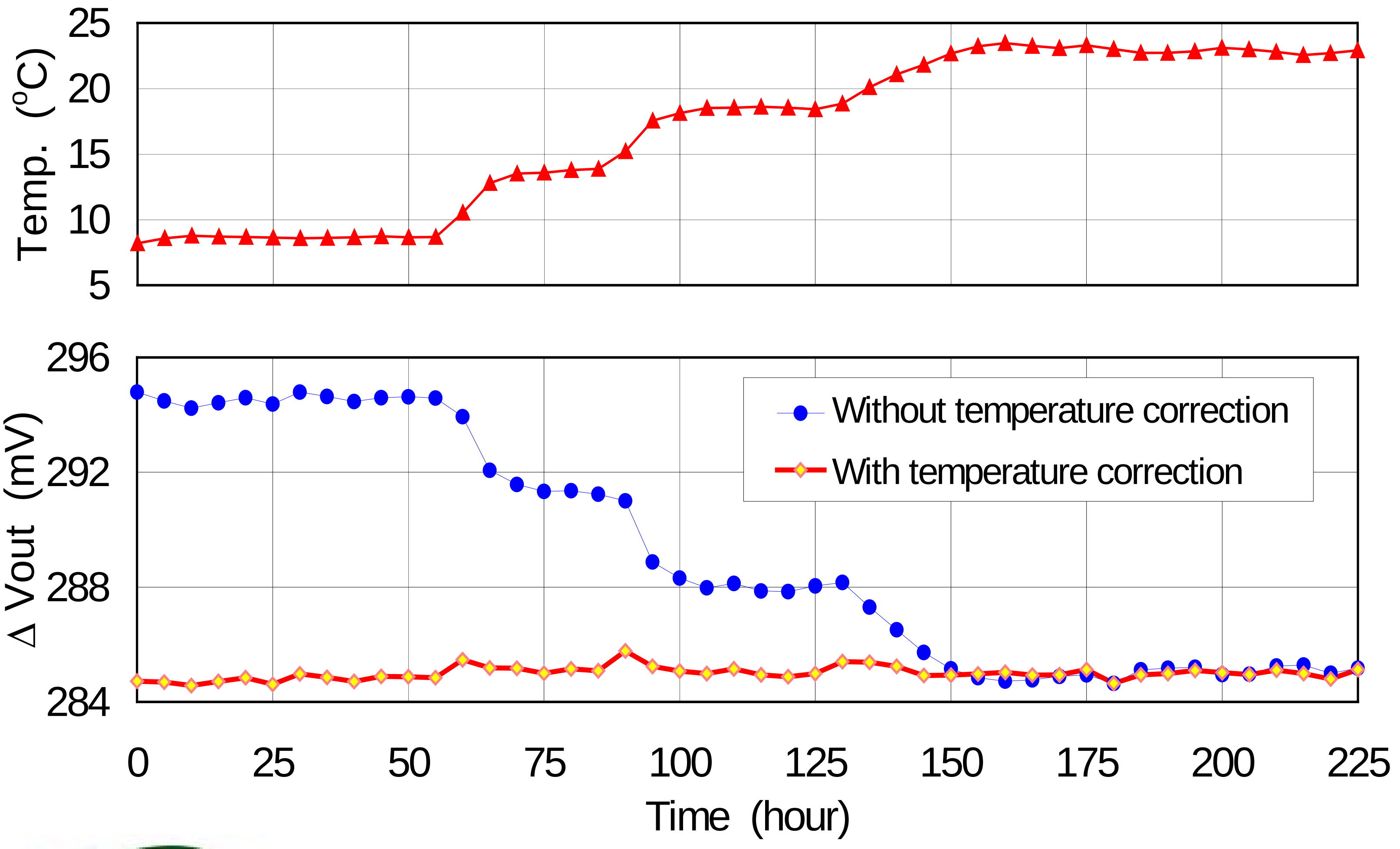
Influence of Soil Temperature (soil suction = 10 kPa)

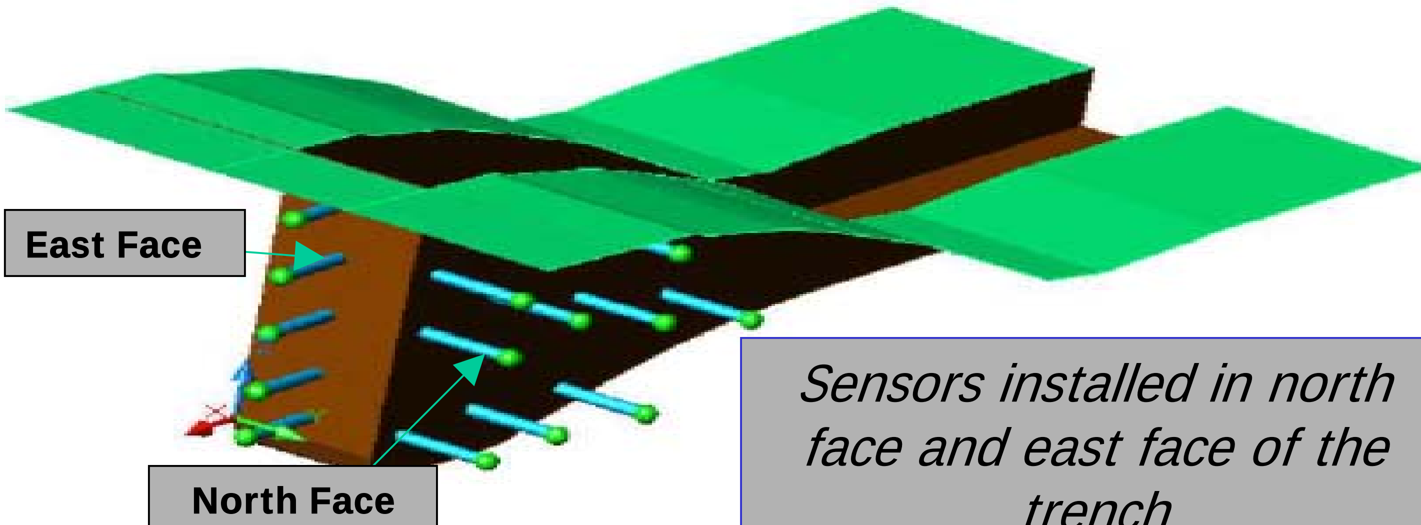


Unsaturated Soil Technology

Site 1 - North of Bethune; Installation completed September 12, 2000

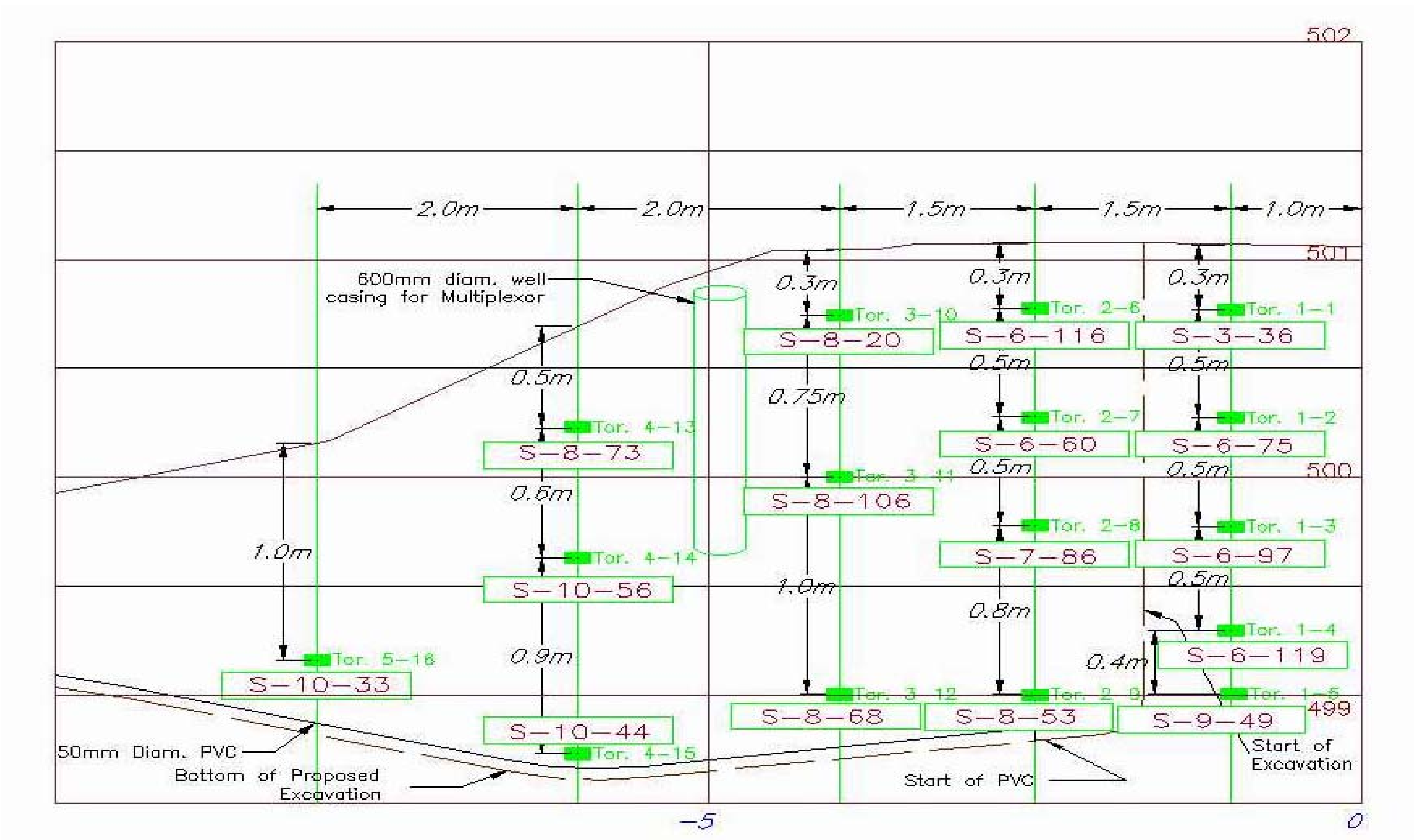
Unsaturated Soil Technology

Reversed 3D Section Showing Installed Thermal Conductivity Suction Sensors



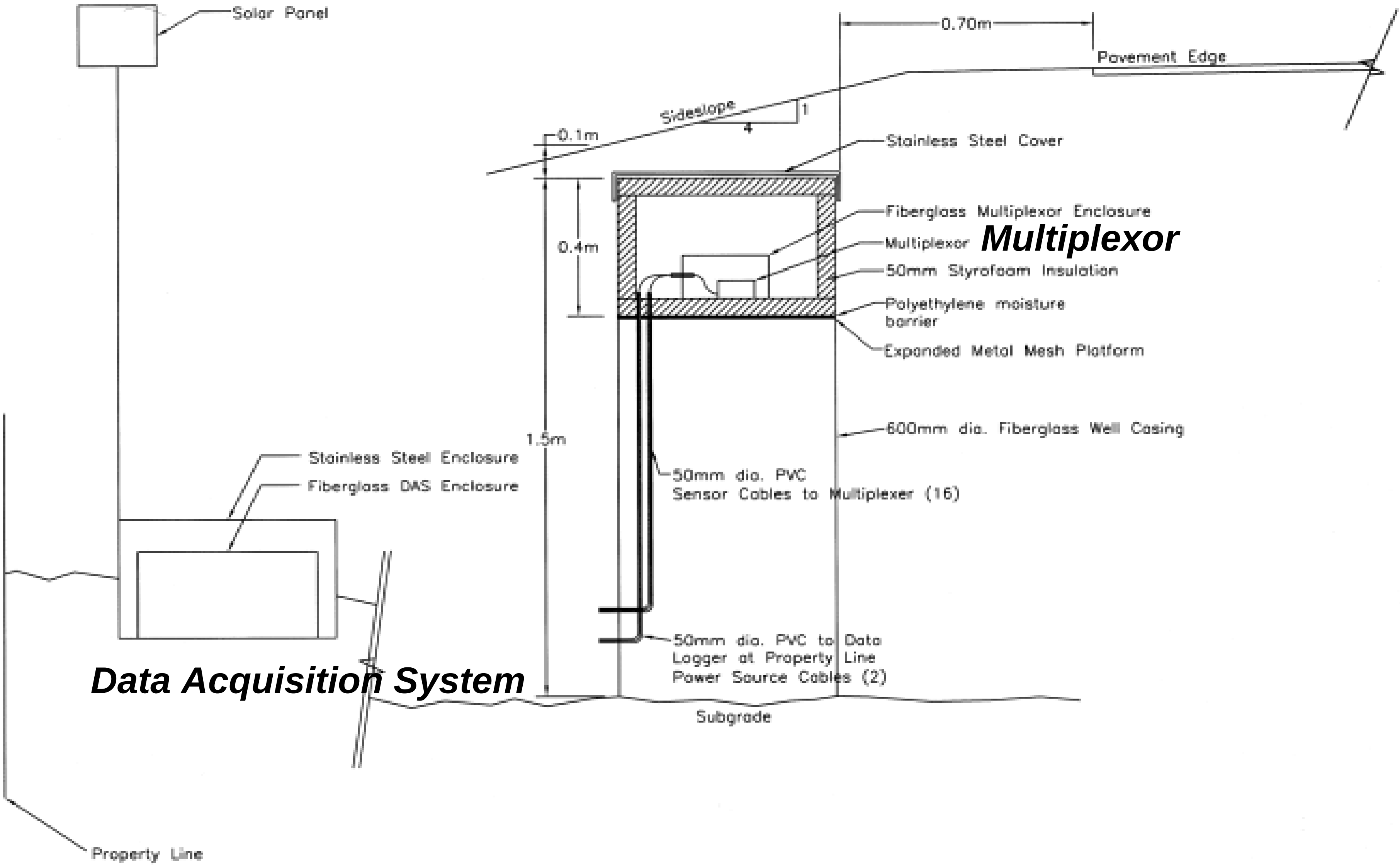
Sensors installed in north face and east face of the trench

Grid of Sensor Installations
Torquay Site



Clean out sensor hole using compressed air

Design variation between Site 1 and Site 2

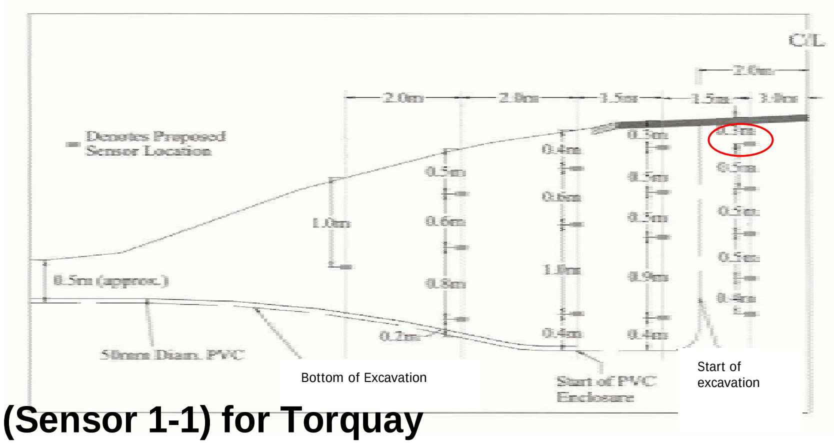


Data Acquisition System

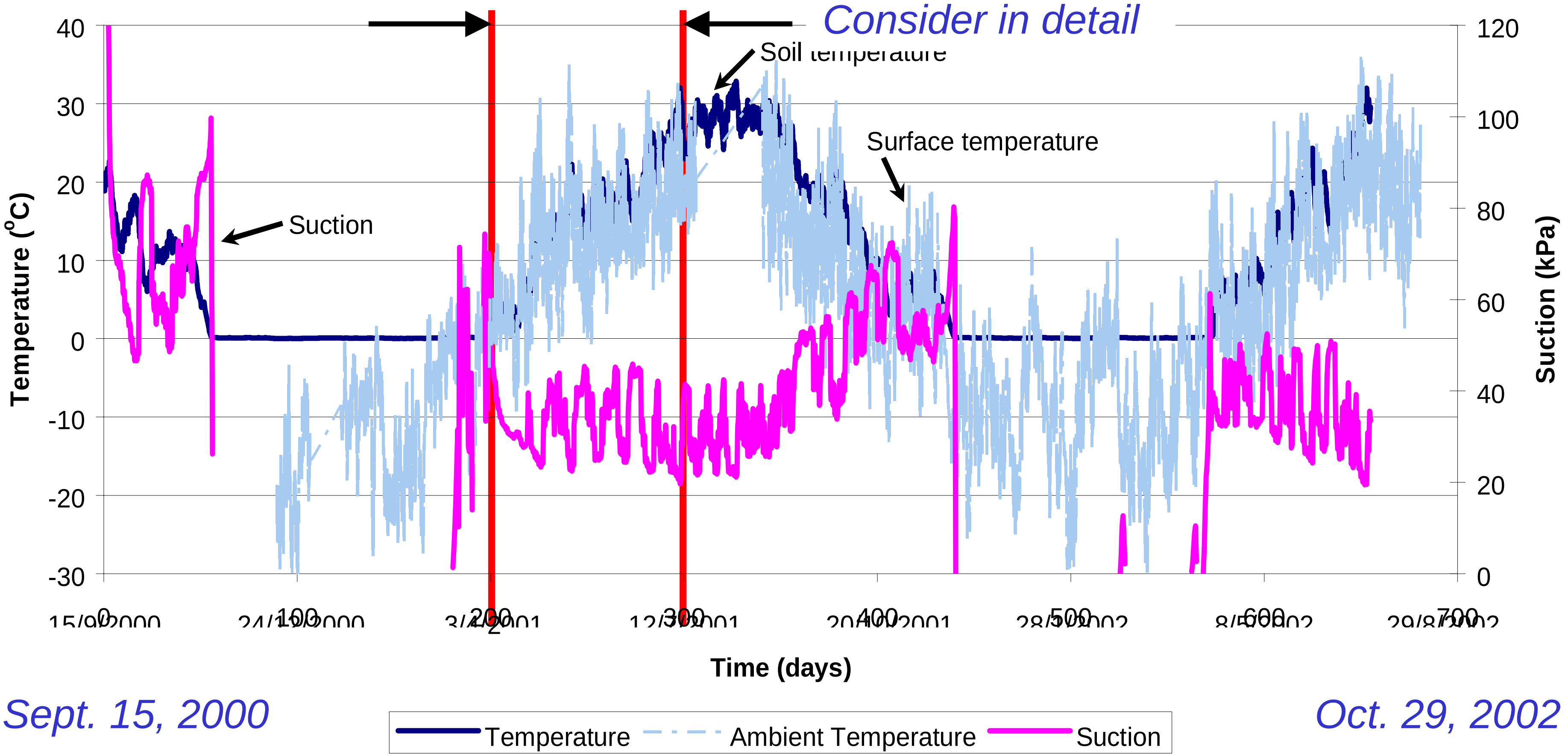
Completed Installation Viewed from the Shoulder of the Road

Unsaturated Soil Technology

Torquay Site, Sask



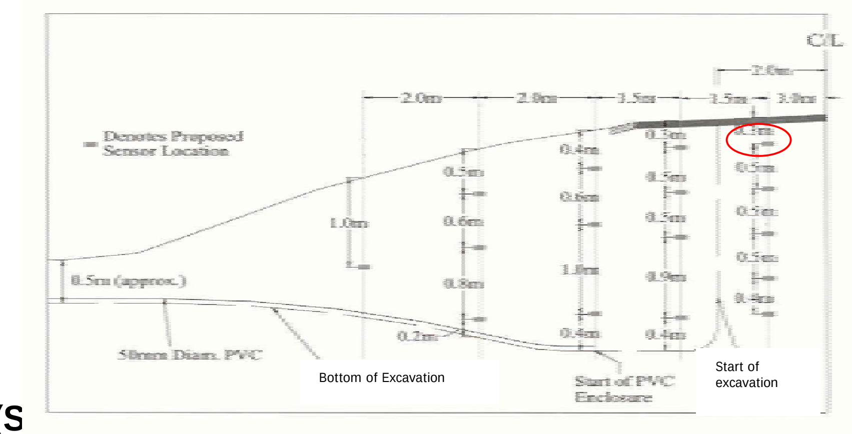
Temperature and Suction versus Time (Sensor 1-1) for Torquay



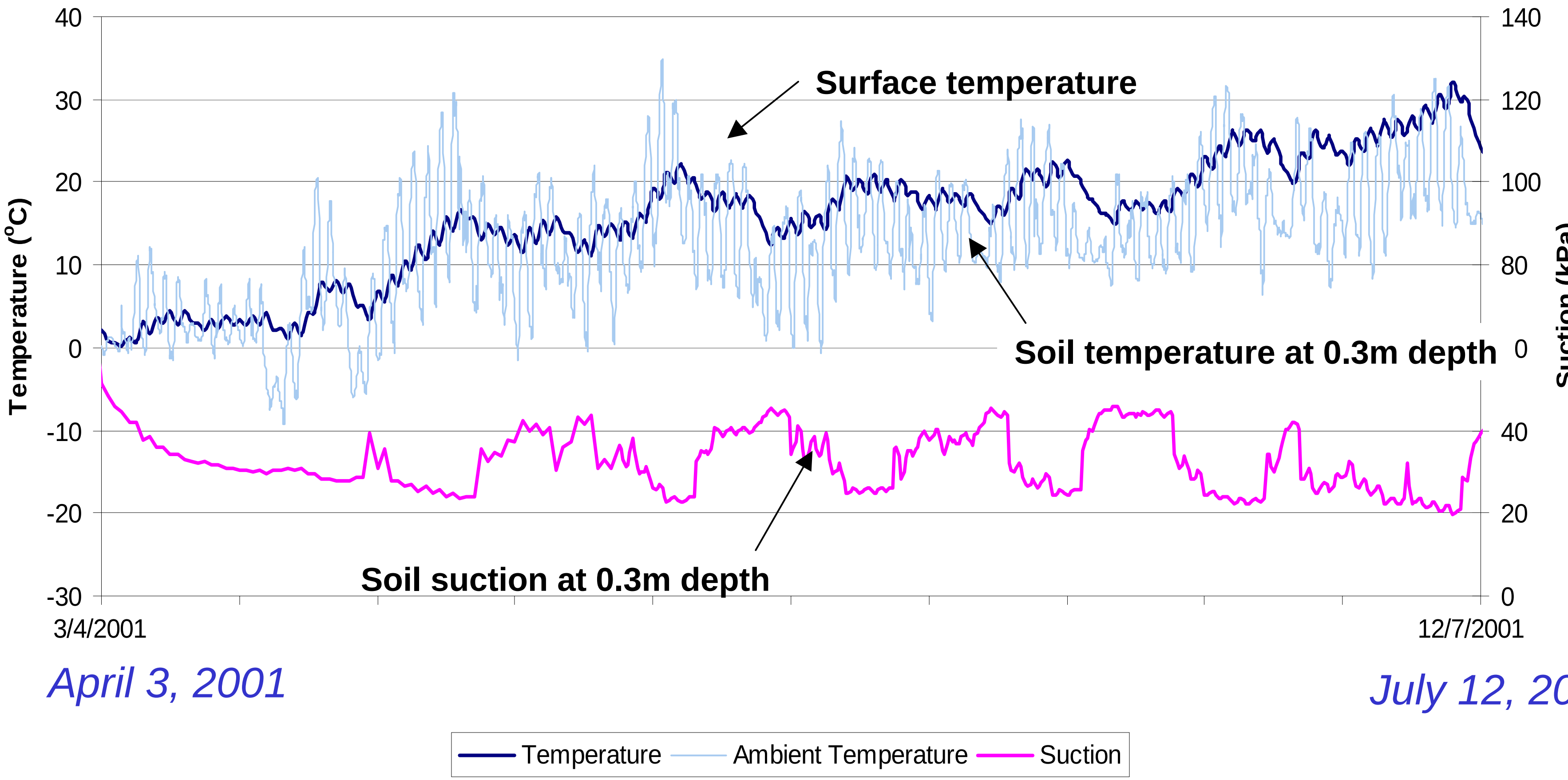
Sept. 15, 2000

Oct. 29, 2002

Torquay Site, Sask



Temperature and Suction versus Time (S

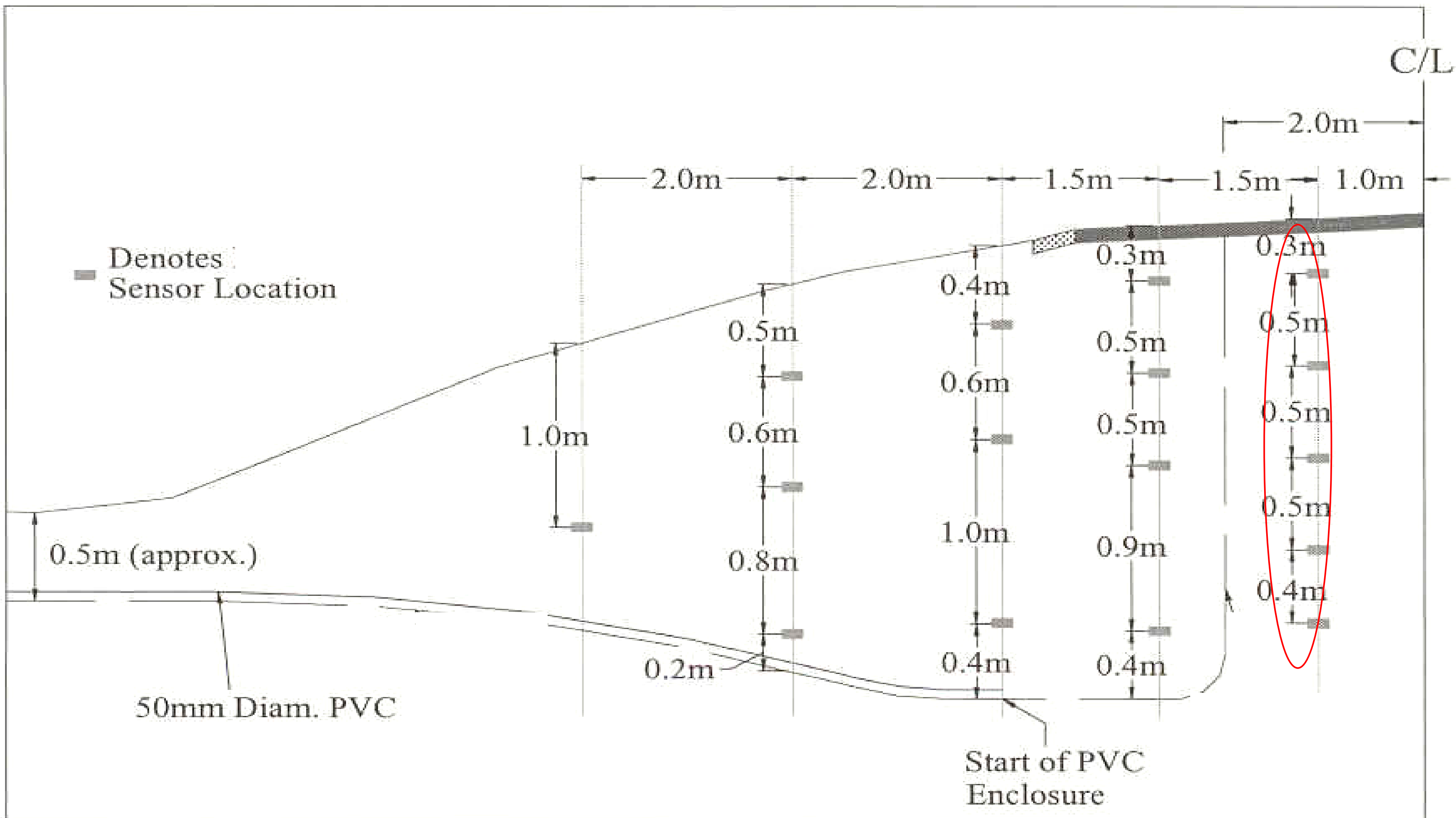


April 3, 2001

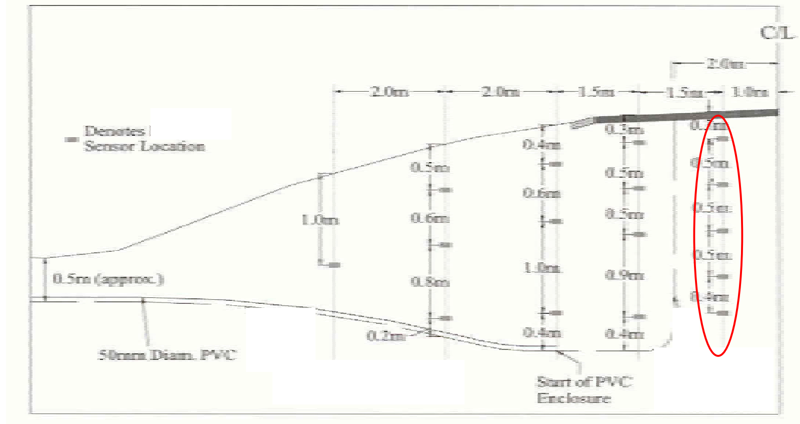
July 12, 2001

Torquay Site, Sask

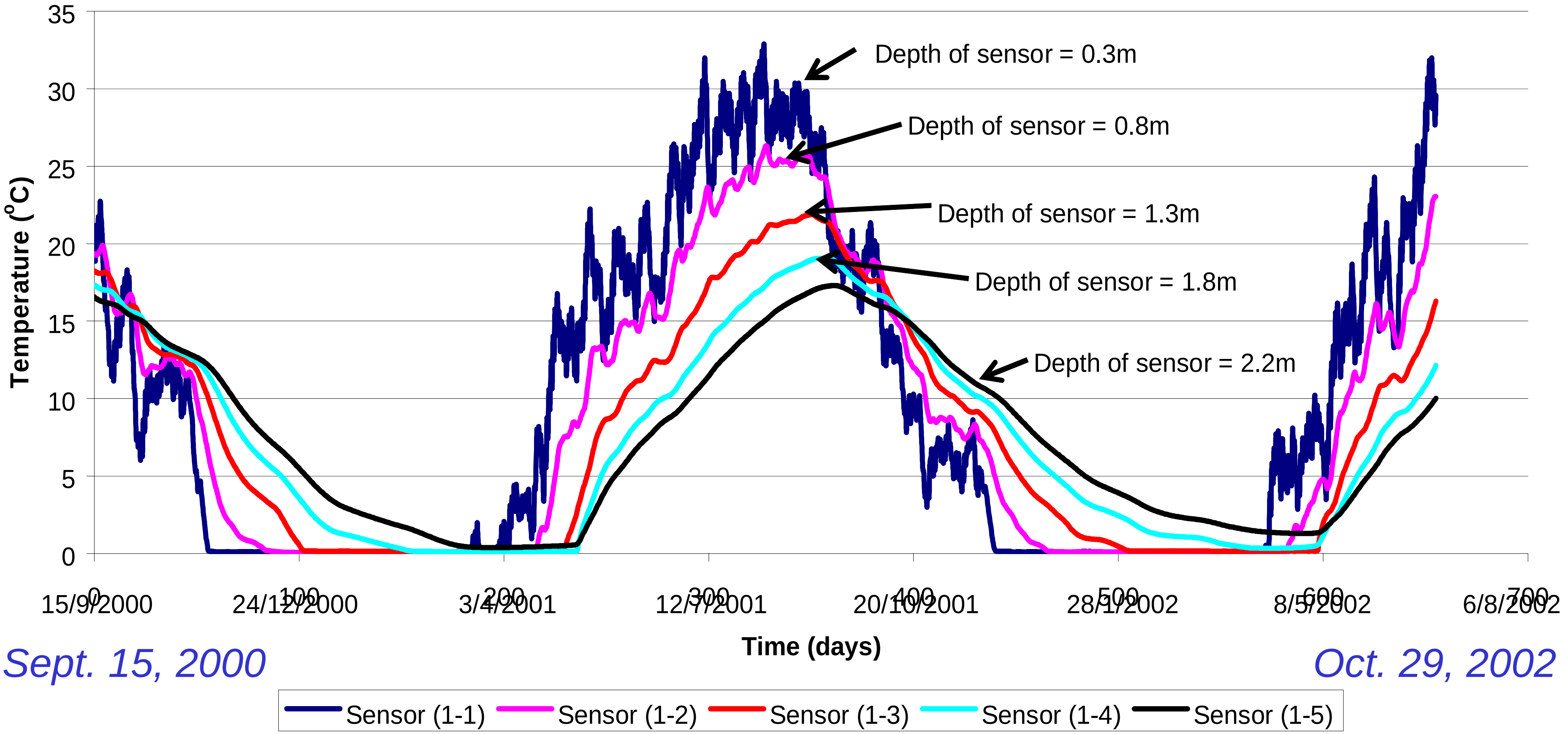
Vertical Grid 1



Torquay Site, Sask



Temperature versus Time for Sensors Along Vertical Grid 1 (Torquay)



Sept. 15, 2000

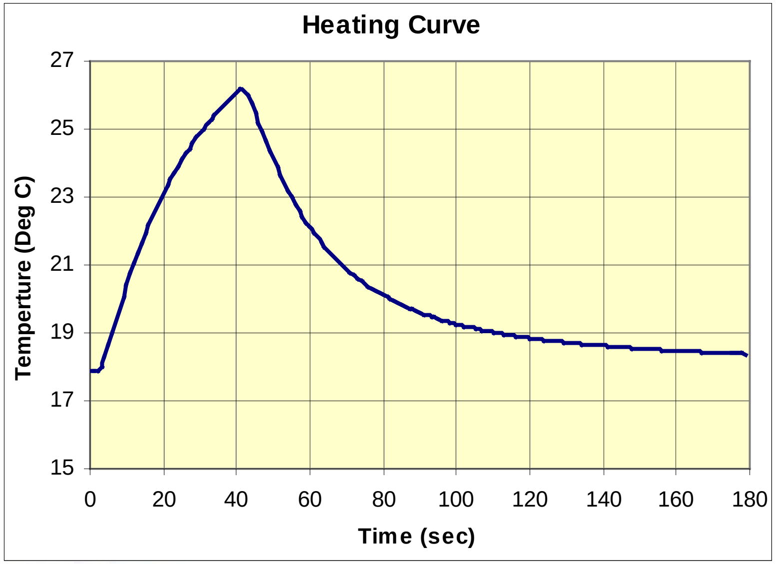
Oct. 29, 2002

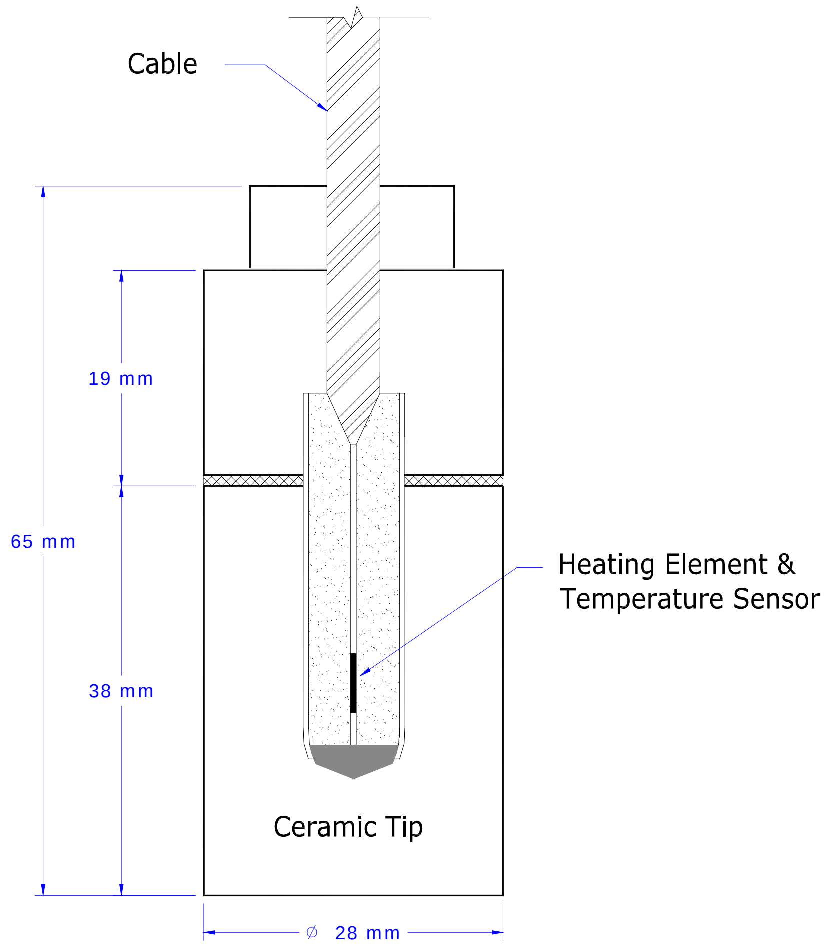
FTC – 100 Suction Sensor

GCTS
Geotechnical Consulting and Testing Systems

Email: mpadilla@gcts.com

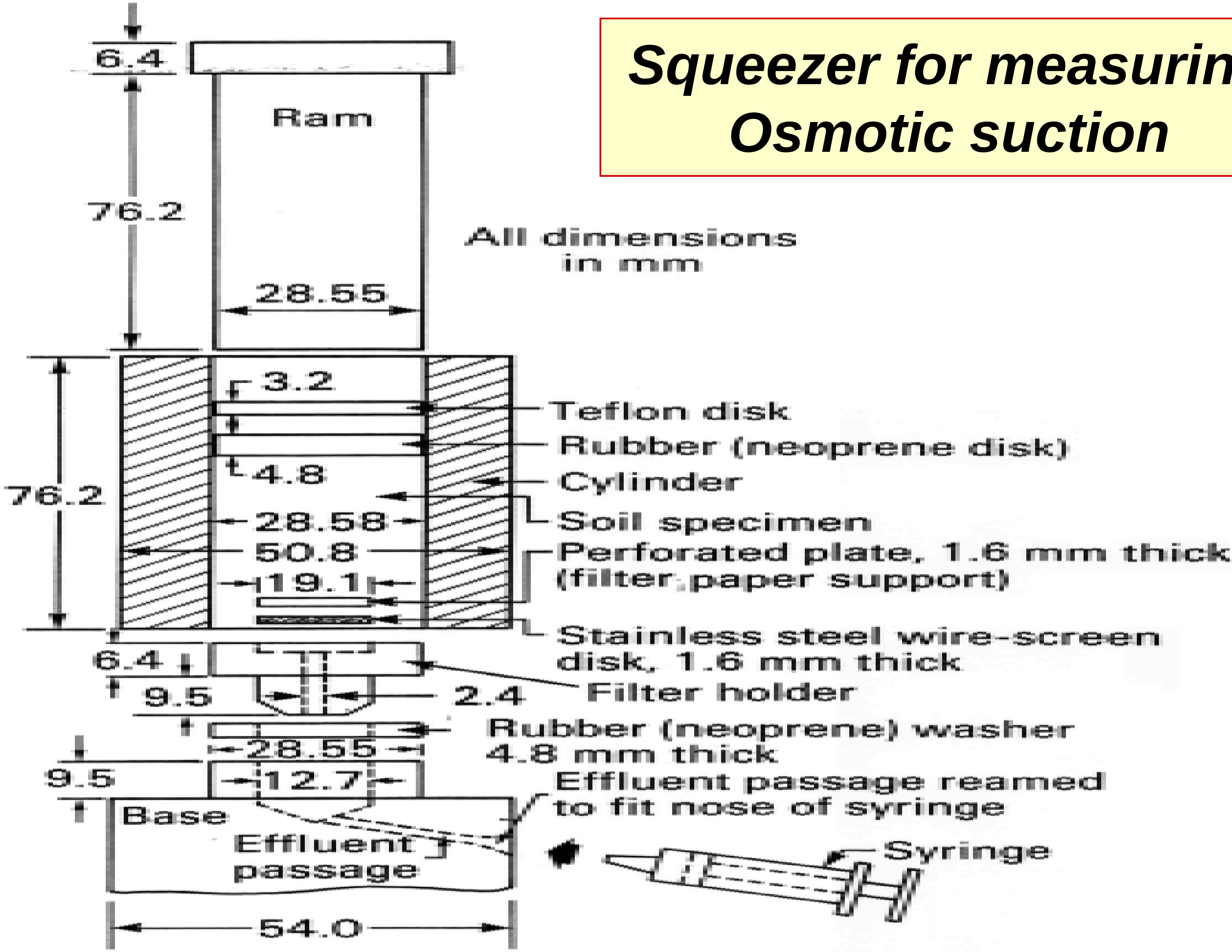
www.gcts.com



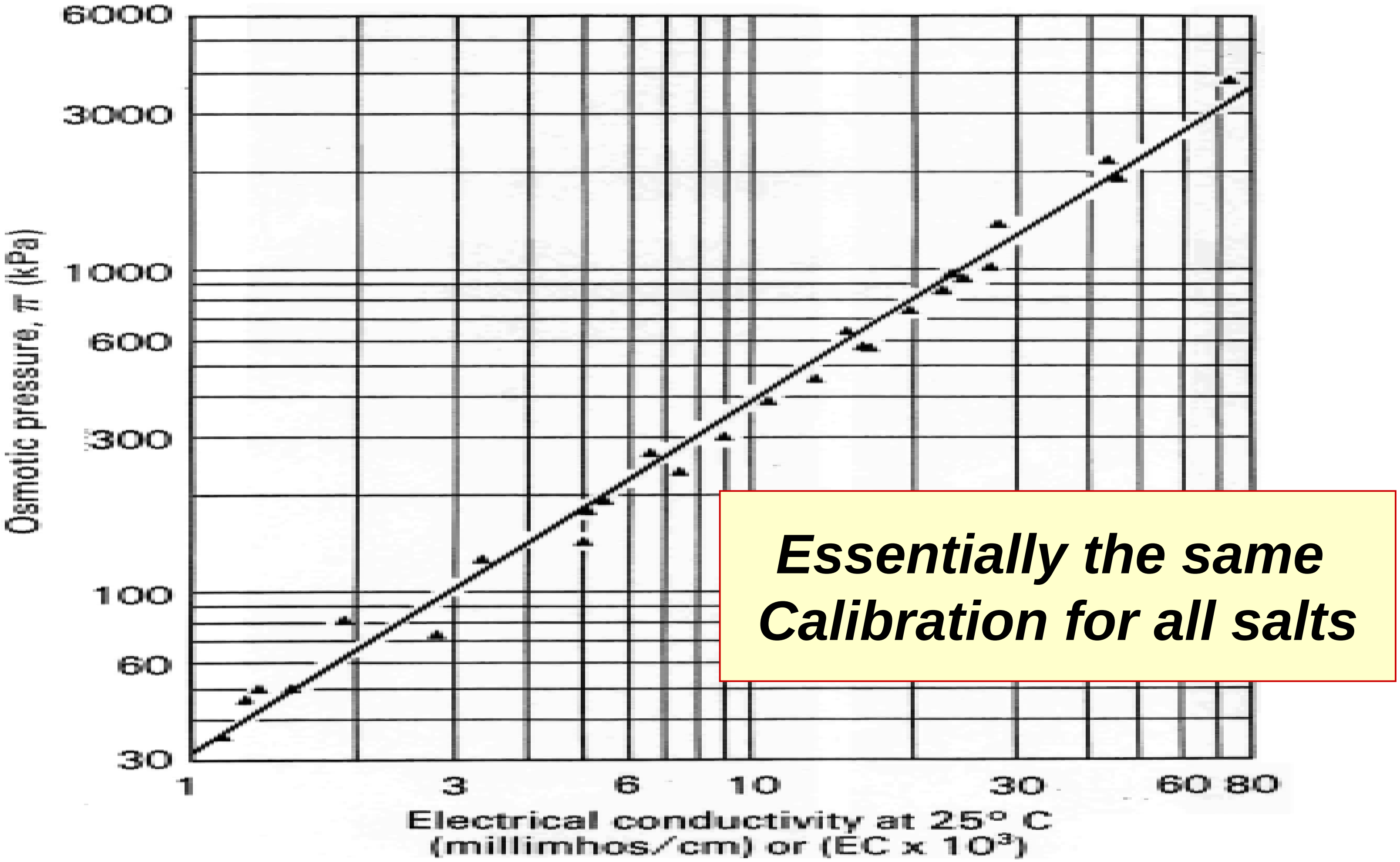


Unsaturated Soil Technology

Squeezer for measuring Osmotic suction



The design of the pore fluid squeezer (from Manheim, 1966)



Osmotic pressure versus electrical conductivity relationship for pore-water containing mixtures of dissolved salts (from USDA Agricultural Handbook No. 60,1950)