

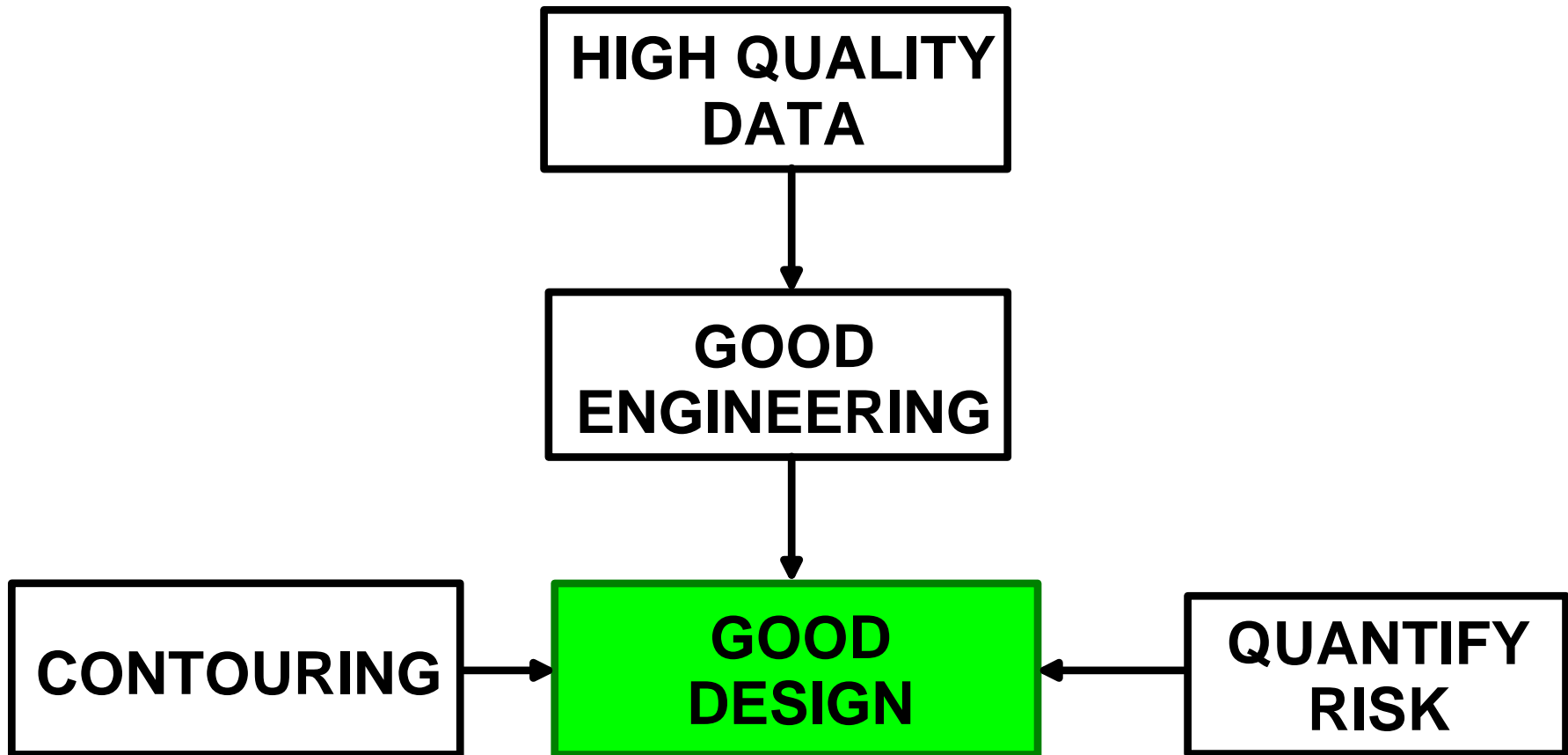


The Importance of Measuring

Roger A. Failmezger, P.E.

Engineering Fees comprise only
1% of the project's life cycle
costs, yet engineering determines
what the other 99% will be.

(Bachner, 1991)





Site Characterization Objectives

- ◆ Quantify soil properties
- ◆ Chosen tests must measure or model property of interest
- ◆ Minimize parasitic test error
- ◆ Assess variability of properties
- ◆ More heterogeneous the site—more tests needed



In-Situ Tests

- ◆ Standard Penetration Test (SPT)
- ◆ Pressuremeter Test (PMT)
- ◆ Electric Cone Penetrometer Test (CPTU)
- ◆ Dilatometer Test (DMT)
- ◆ Borehole Shear Test (BST)



SPT Advantages

- ◆ Readily available
- ◆ Engineering design is straight-forward and simple
- ◆ Can penetrate and test all soil/rock formations
- ◆ Adequate when there is really only one practical engineering design solution



SPT Disadvantages

- ◆ Remolds soil and destroys important soil structure
- ◆ Commonly performed at 1.5m intervals
- ◆ Dynamic test—does not measure static properties
- ◆ Energy rarely calibrated—can vary by a magnitude of 3
- ◆ Test method has changed since primary correlations were made in 1940-1960's



SPT-The Big Guess!

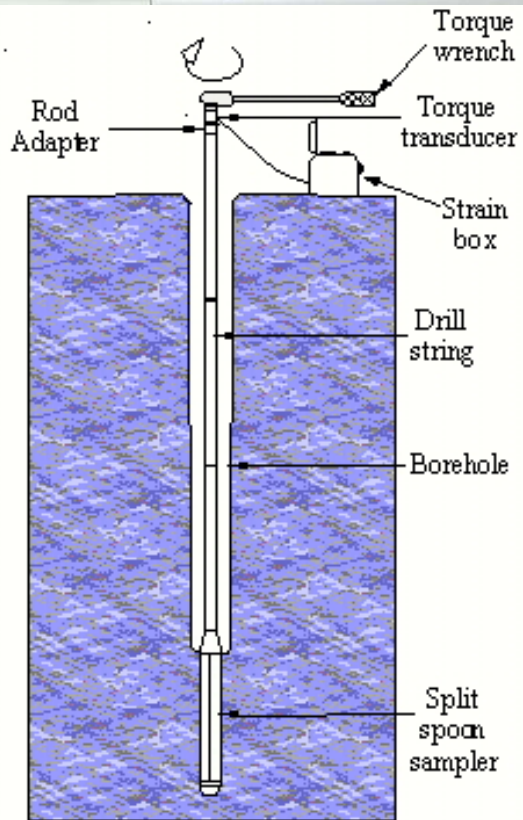
- ◆ Test error causes high uncertainty—can lead to overly conservative and very costly designs
- ◆ Fairly homogeneous sites will be characterized as heterogeneous



Ways to Improve SPT



- ◆ Calibrate energy
- ◆ Should correct blow counts to N_{60} values
- ◆ Use torque measurements



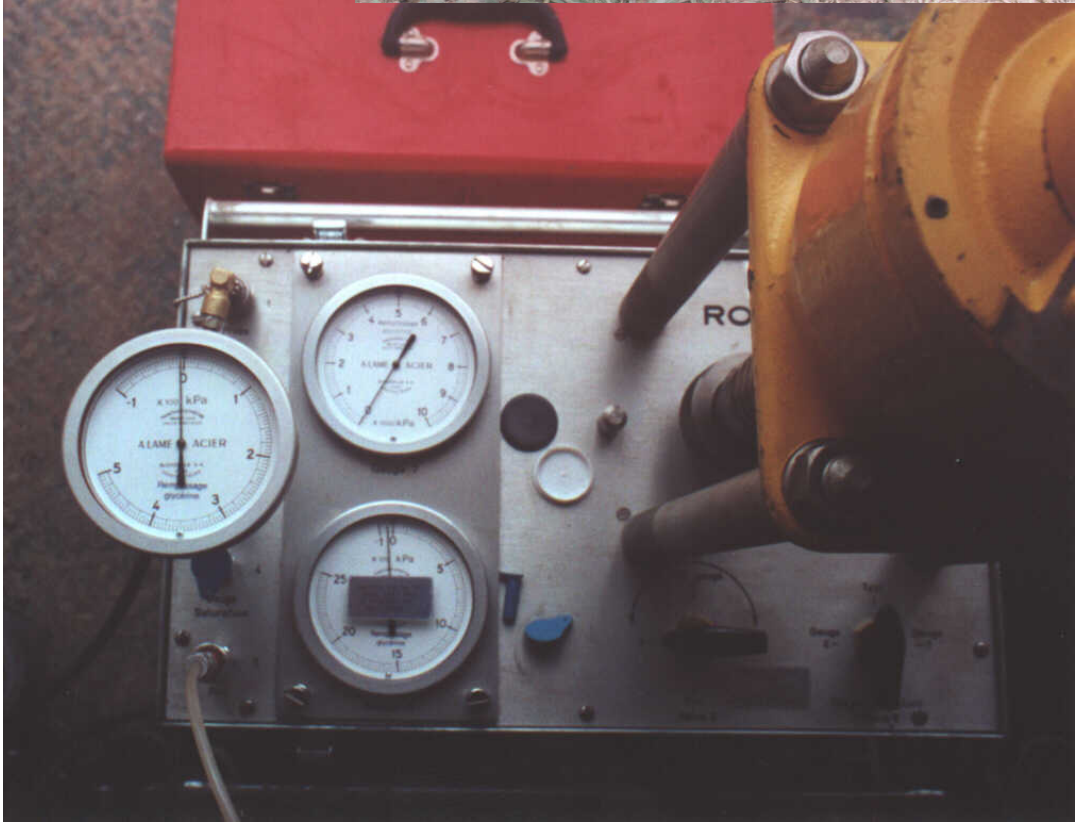
Courtesy of University of Massachusetts

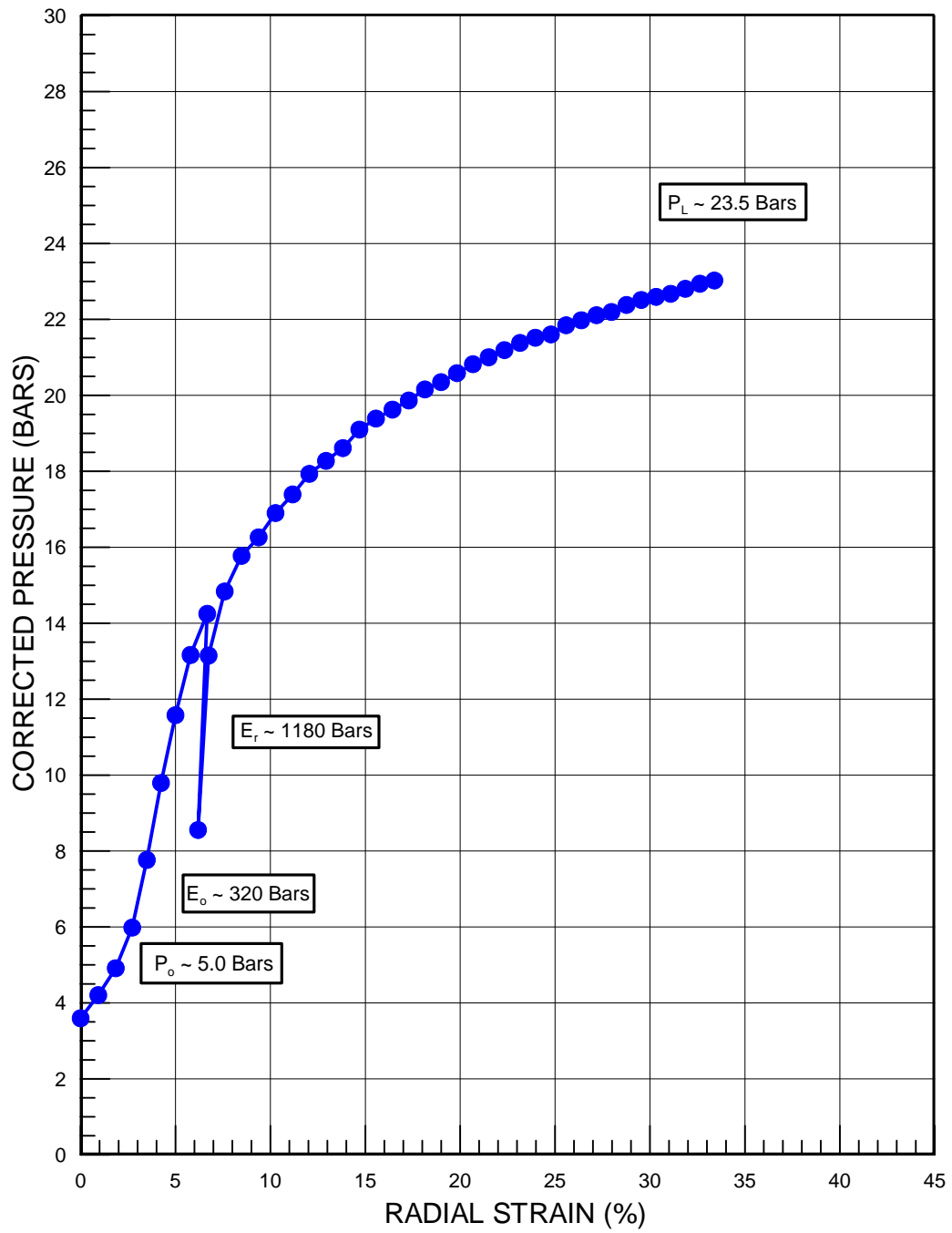


Pressuremeter Test



- ◆ Calibrated static deformation test
- ◆ Requires high quality undisturbed borehole
- ◆ Test interval => 1.5 meter
- ◆ Can test rock

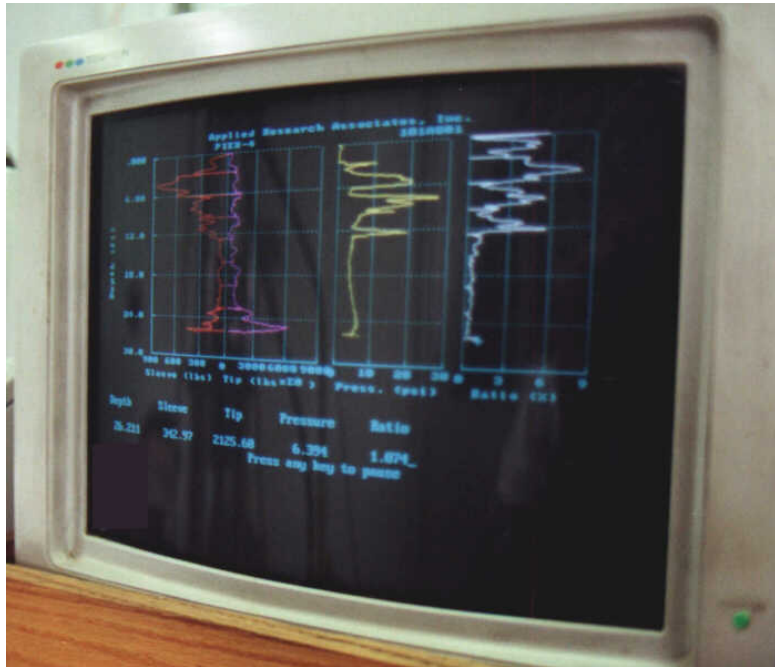


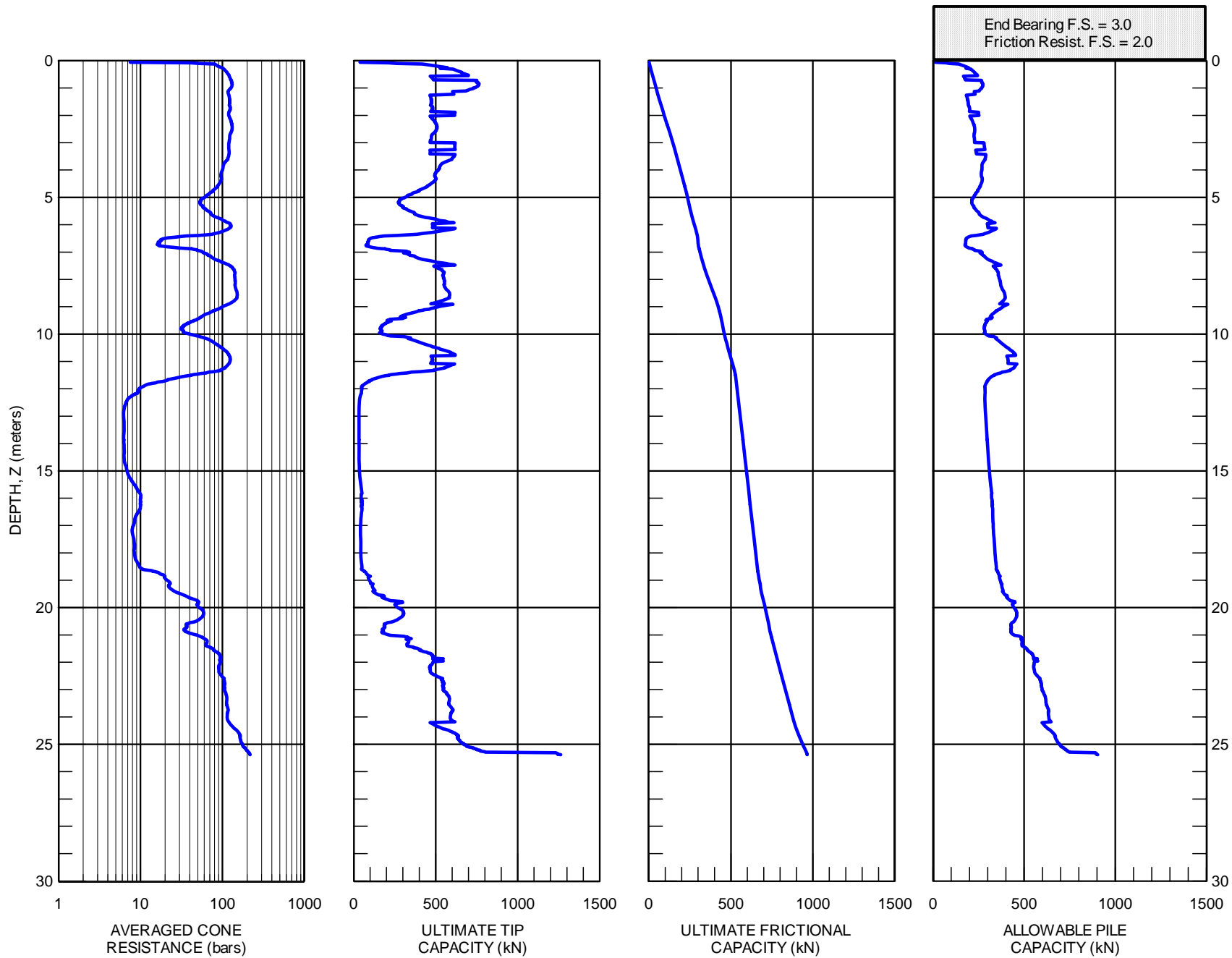




Electric Cone Penetration Test

- ◆ Calibrated quasi-static penetration test
- ◆ Data collected at 0.01 to 0.05m intervals
- ◆ Rapidly characterize sites—identify critical soft zones—find top of rock
- ◆ Vertical pile capacity

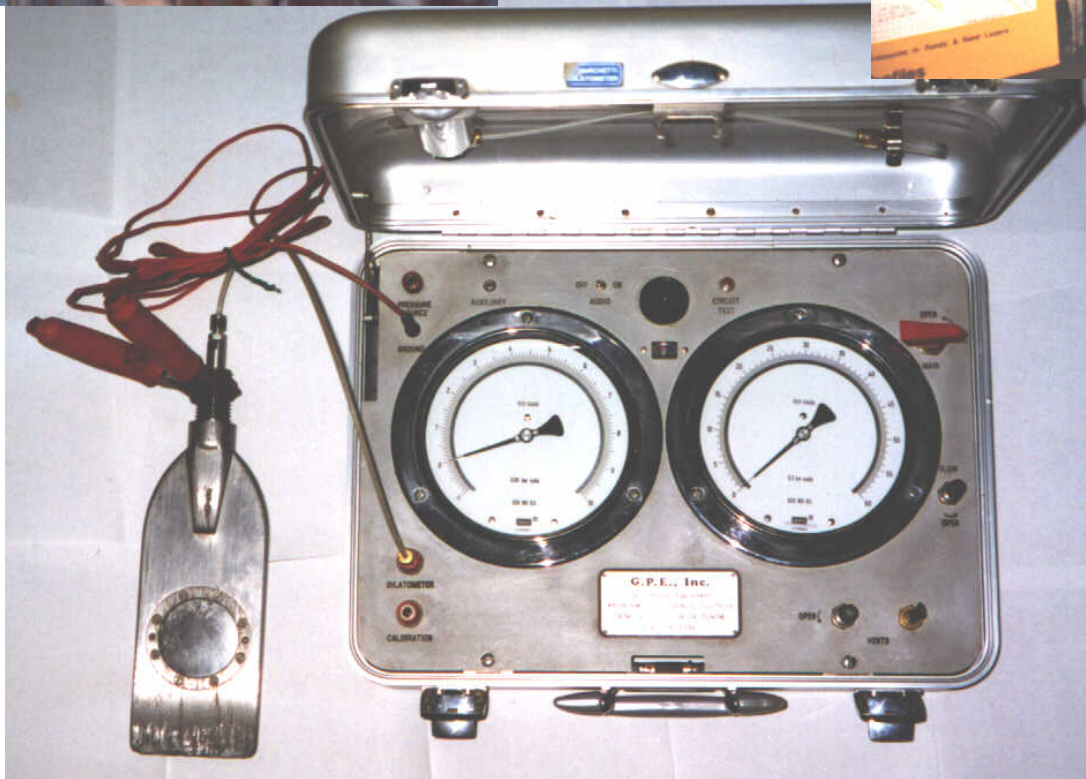






Dilatometer Test

- ◆ Calibrated static deformation test
- ◆ Performed at 0.1 to 0.2m intervals
- ◆ Low volumetric and shear strain induced during penetration—measures significance of lateral stress
- ◆ Accurately measures deformation modulus and undrained shear strength

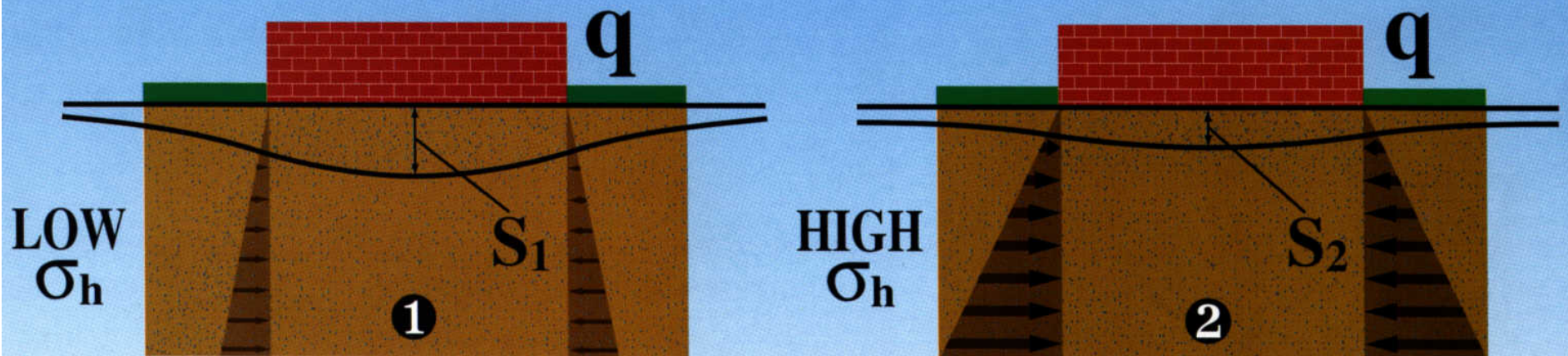


Importance of Lateral Stress (Schmertmann, 1985)

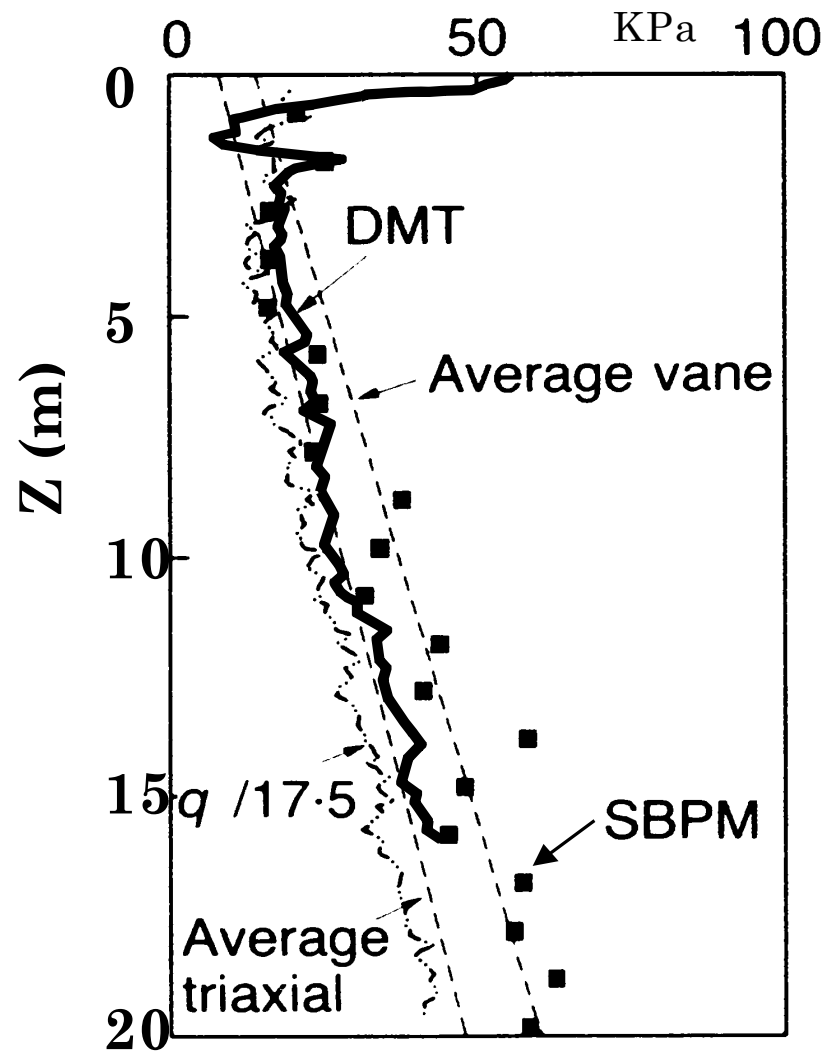
◆ Eng. Behavior	Low K	High K
■ Bearing Capacity		← safety decreases
■ Slope Stability		← safety decreases →
■ Pressure on Walls		← increases →
■ Pile Friction		← decreases
■ Settlement		← increases
■ Ground Improvement		← more difficult →

σ_h important for SETTLEMENTS

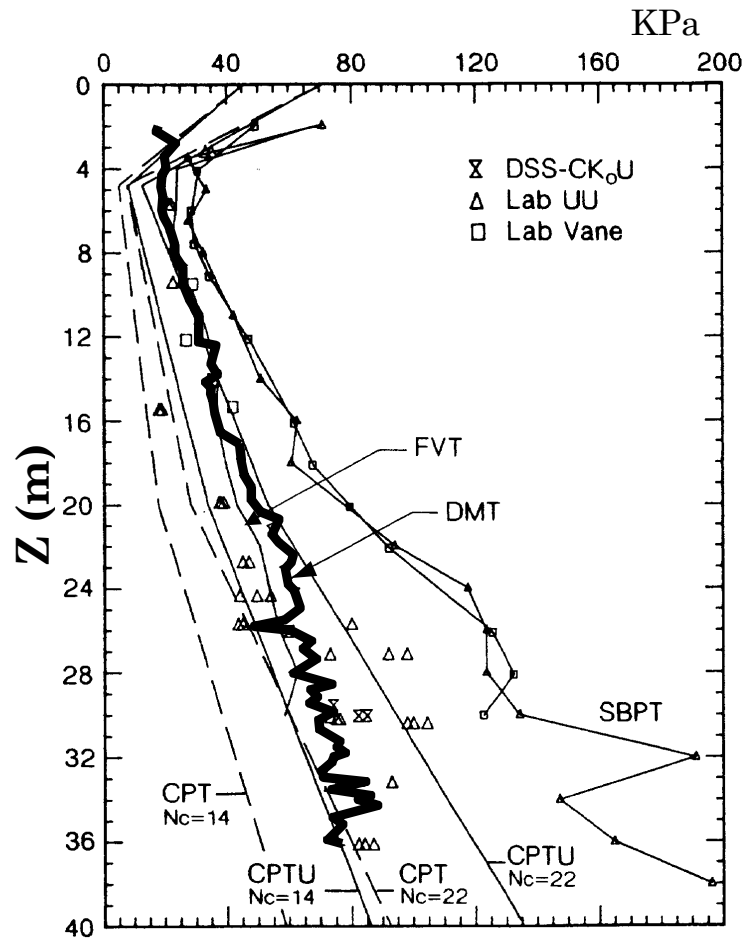
same sand, same q : $S_2 \ll S_1$



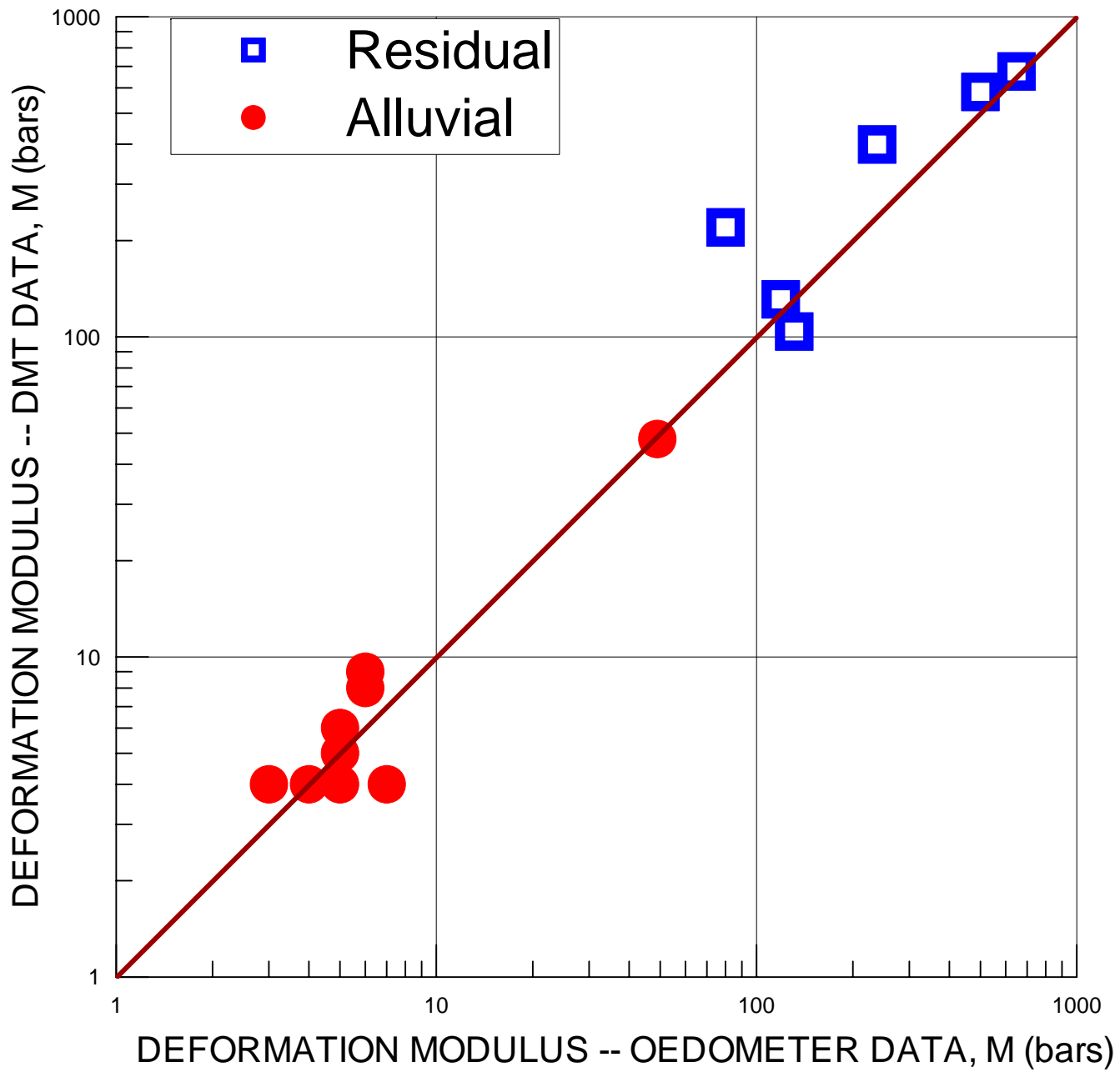
Cu at NATIONAL SITE BOTHKENNAR



Cu at NATIONAL SITE FUCINO



$N_c = 10$ to 20 or 14 to 22 ?





Borehole Shear Test

- ◆ Calibrated static test
- ◆ Accurately measures drained shear strength
- ◆ Compares very well with laboratory triaxial shear strength test results
- ◆ Requires minimal disturbance to borehole sidewalls



BOREHOLE SHEAR TEST

Project:

Location:

Engineer: R. Failmezger

Date: 11/23/99

Borehole: A

Test No. 2

Depth: 9.05 m

Water Depth: 5.85 m

Shear Plates: 2" x 2.5"

= 5.0 in²

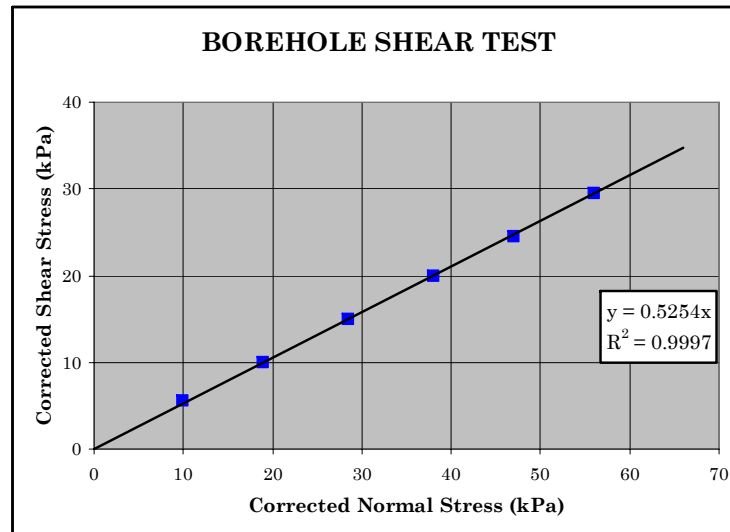
Method: Stage

Initial Normal Gauge Reading = 20 kPa

Initial Shear Gauge Reading = 10.5 kPa

Calibration Factor = 1.0 [Use 6.25 for high pressure plates]

Test Data				Remarks
Normal Stress Gauge Reading (kPa)	Shear Stress Gauge Reading (kPa)	Corrected Normal Stress (kPa)	Corrected Shear Stress (kPa)	
30.0	16.0	10.0	5.5	
39.0	20.5	19.0	10.0	
48.5	25.5	28.5	15.0	
58.0	30.5	38.0	20.0	
67.0	35.0	47.0	24.5	
76.0	40.0	56.0	29.5	
Drained Angle of Internal Friction =			27.7	
Effective Cohesion (kPa) =			0.0	





Undisturbed Sampling



- ◆ Use electric cone penetrometer or dilatometer tests to identify critical zones for undisturbed sampling
- ◆ Use piston samplers
- ◆ Perform laboratory tests as soon as possible



Predicting Settlement of Shallow Foundations

- ◆ Dilatometer and pressuremeter best choices because they are calibrated deformation tests
- ◆ For heterogeneous conditions, DMT better because more tests at closer intervals can be performed

Settlement Using DMT Data

- ◆ $S = (\Delta\sigma)(h)/M$ (Schmertmann, 1986)
where S = settlement,
 $\Delta\sigma$ = vertical stress increase,
 h = layer thickness, and
 M = constrained deformation modulus.

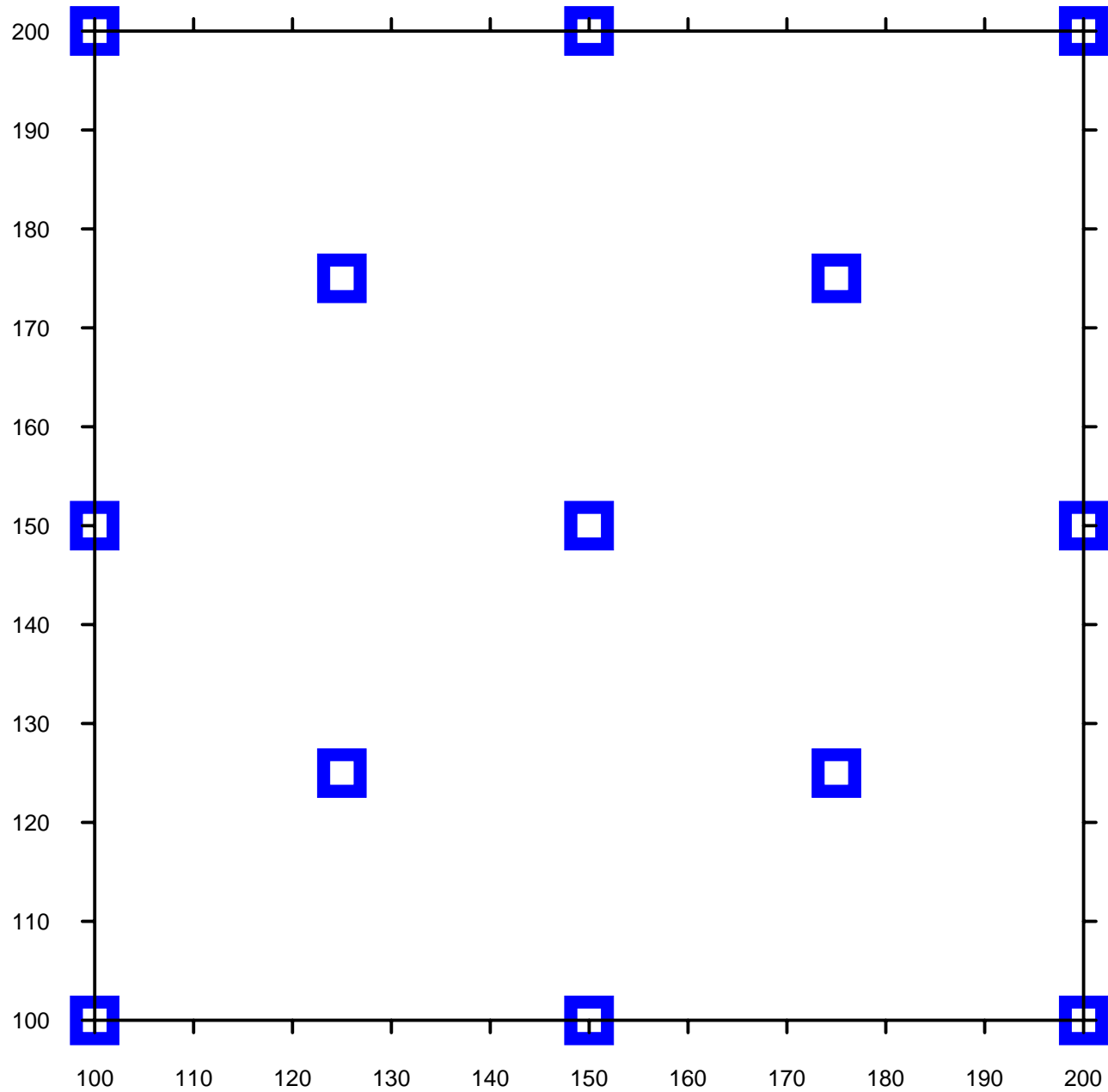


Contouring for Bridges

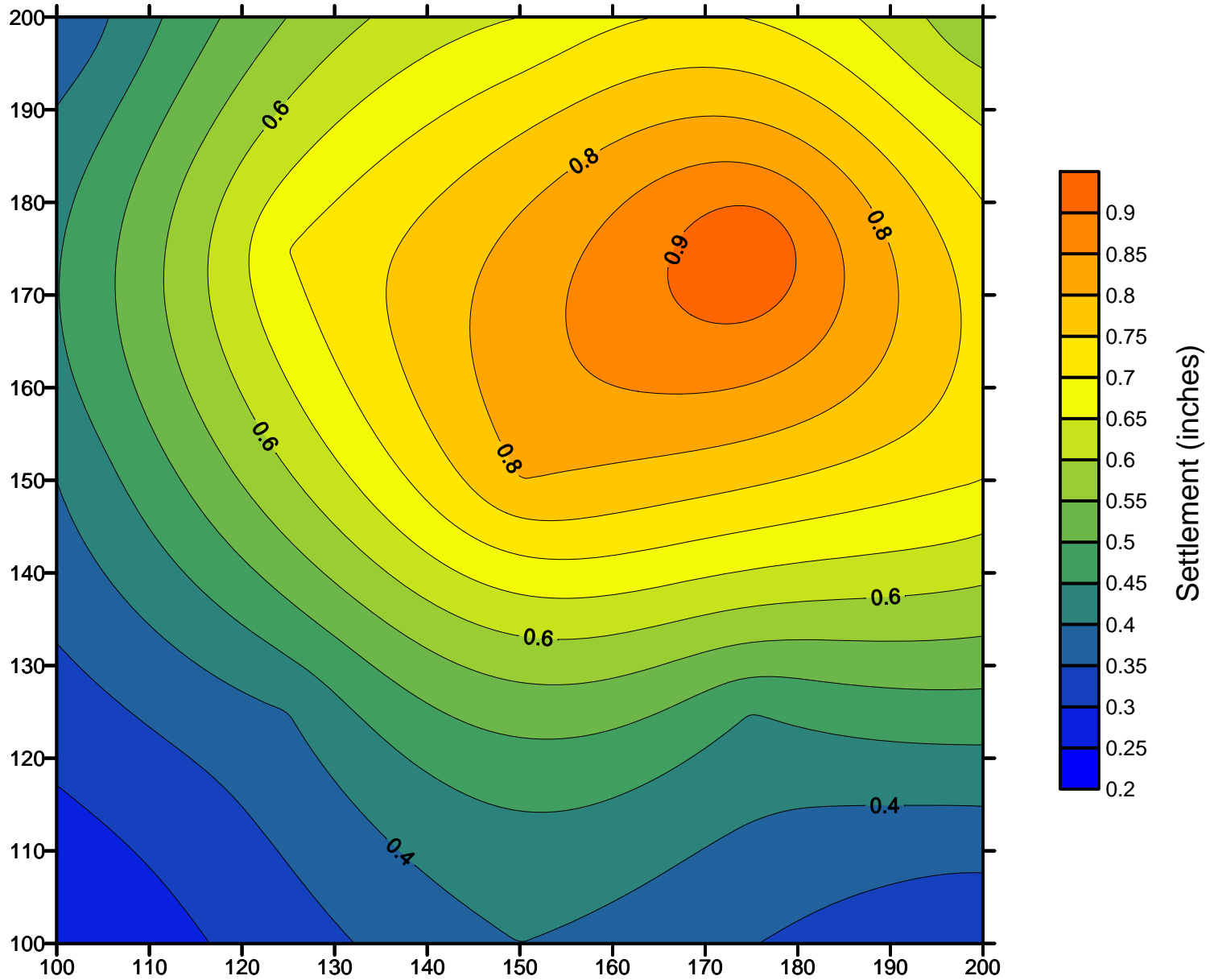


- ◆ Finite Number of Test Locations—Provides Numeric Interpretation between Locations
- ◆ Requires continuous or near-continuous data
- ◆ Settlement Contour Map
 - Suitable area for Embankment
 - Marginal soils—Ground Improvement
- ◆ Pile Tip Contour Map

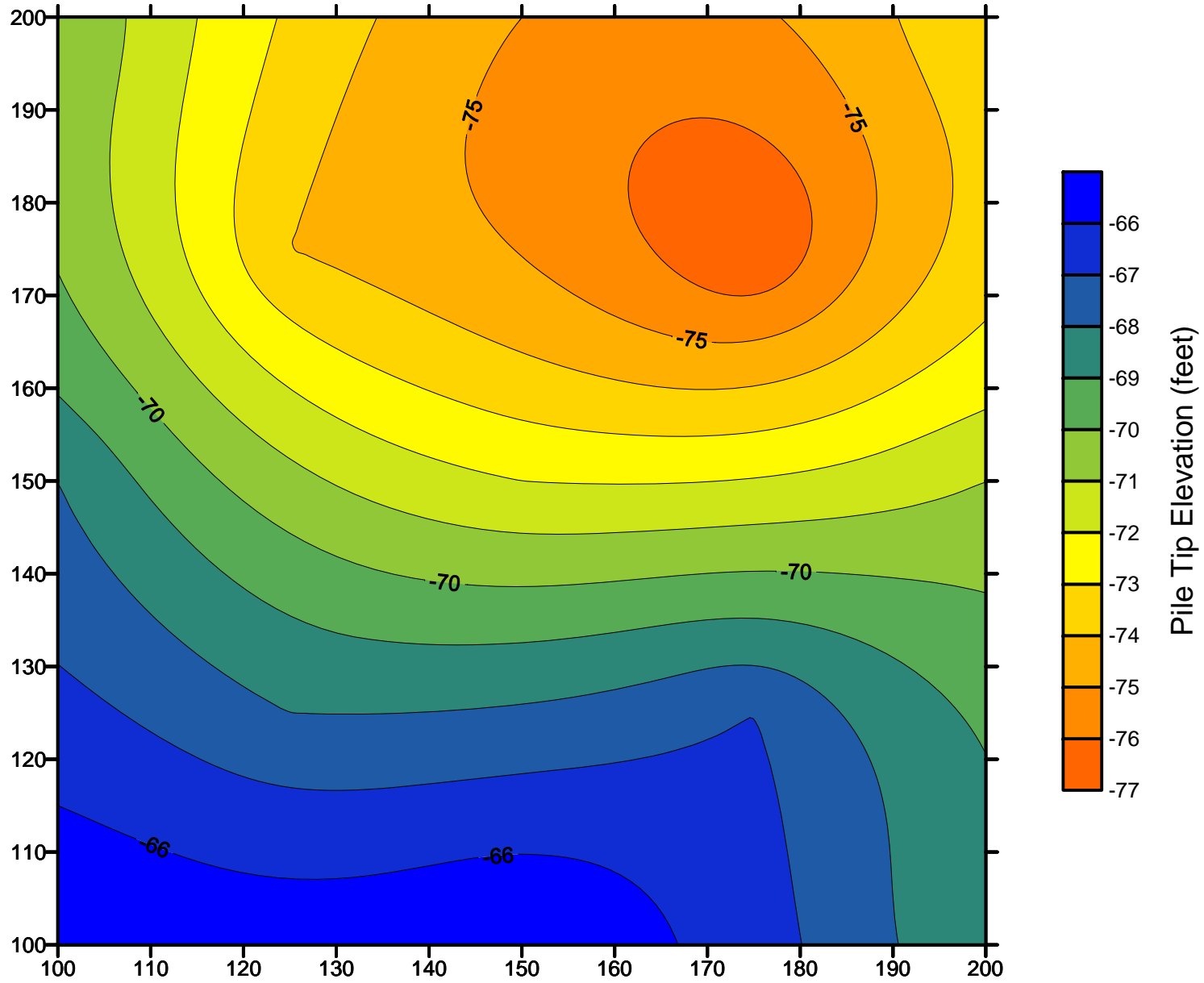
PLAN VIEW FOR PRELIMINARY SOUNDING LOCATIONS



PREDICTED SETTLEMENT FOR PROJECT



PREDICTED PILE TIP ELEVATION FOR PROJECT



Photos Courtesy of S&ME





Quantifying Risk

- ◆ With good quality data, the engineer can quantify risk
- ◆ Average values are not indicative of risk
- ◆ Probability approach instead of factor of safety approach is needed to quantify risk
- ◆ Designs should be less conservative for homogeneous conditions than heterogeneous conditions—less uncertainty
- ◆ Poor quality data can mislead an engineer to believe site is heterogeneous when it is fairly homogeneous



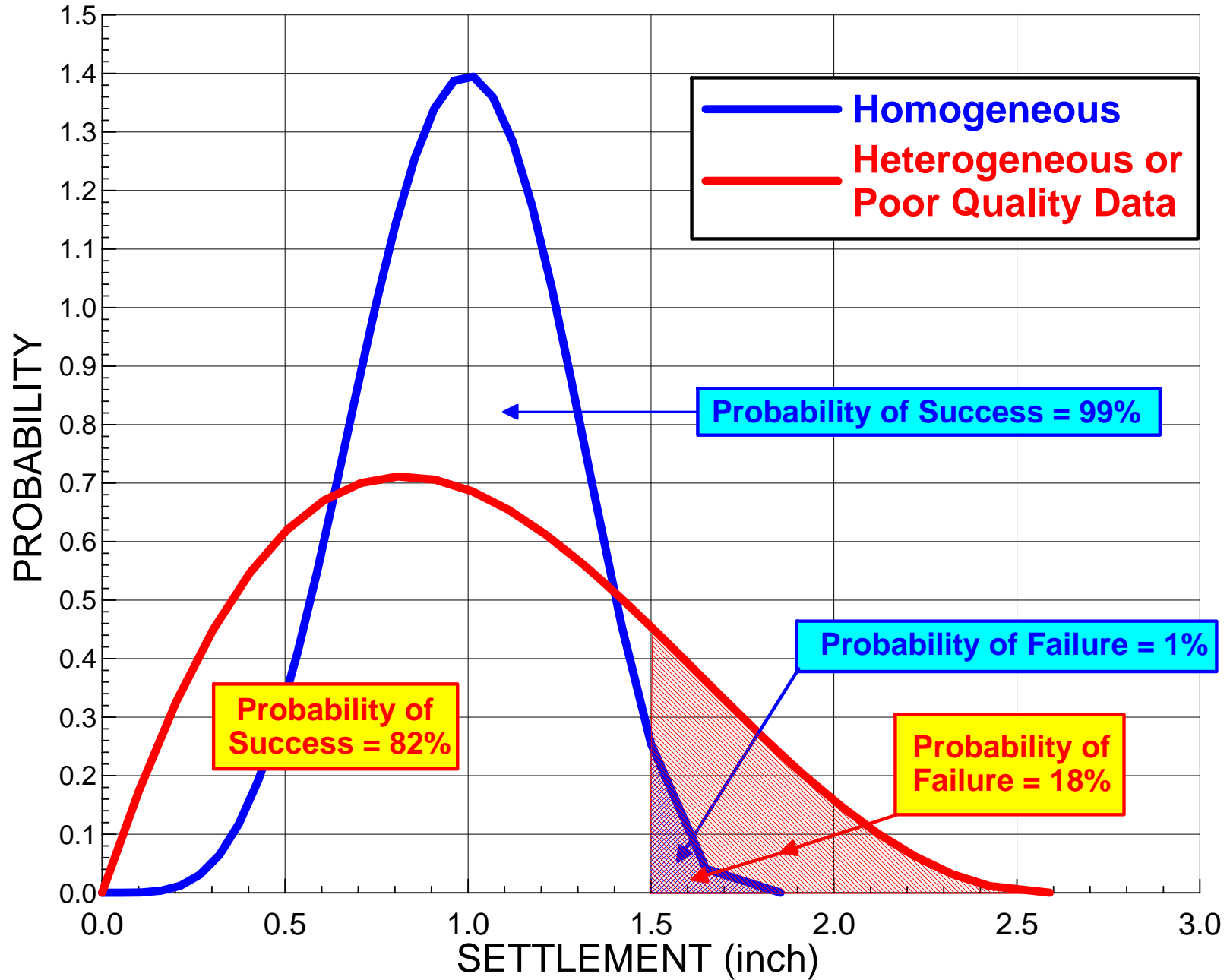
Factor of Safety Disadvantages

- ◆ Engineer assumes a value for F.S. based on engineer's "experience" or local codes
- ◆ Usually does not consider variability of subsurface conditions
- ◆ Experience gained by analyzing failures
- ◆ F.S. = 1.0 is the only value with risk meaning—other values have no quantitative value for risk evaluation

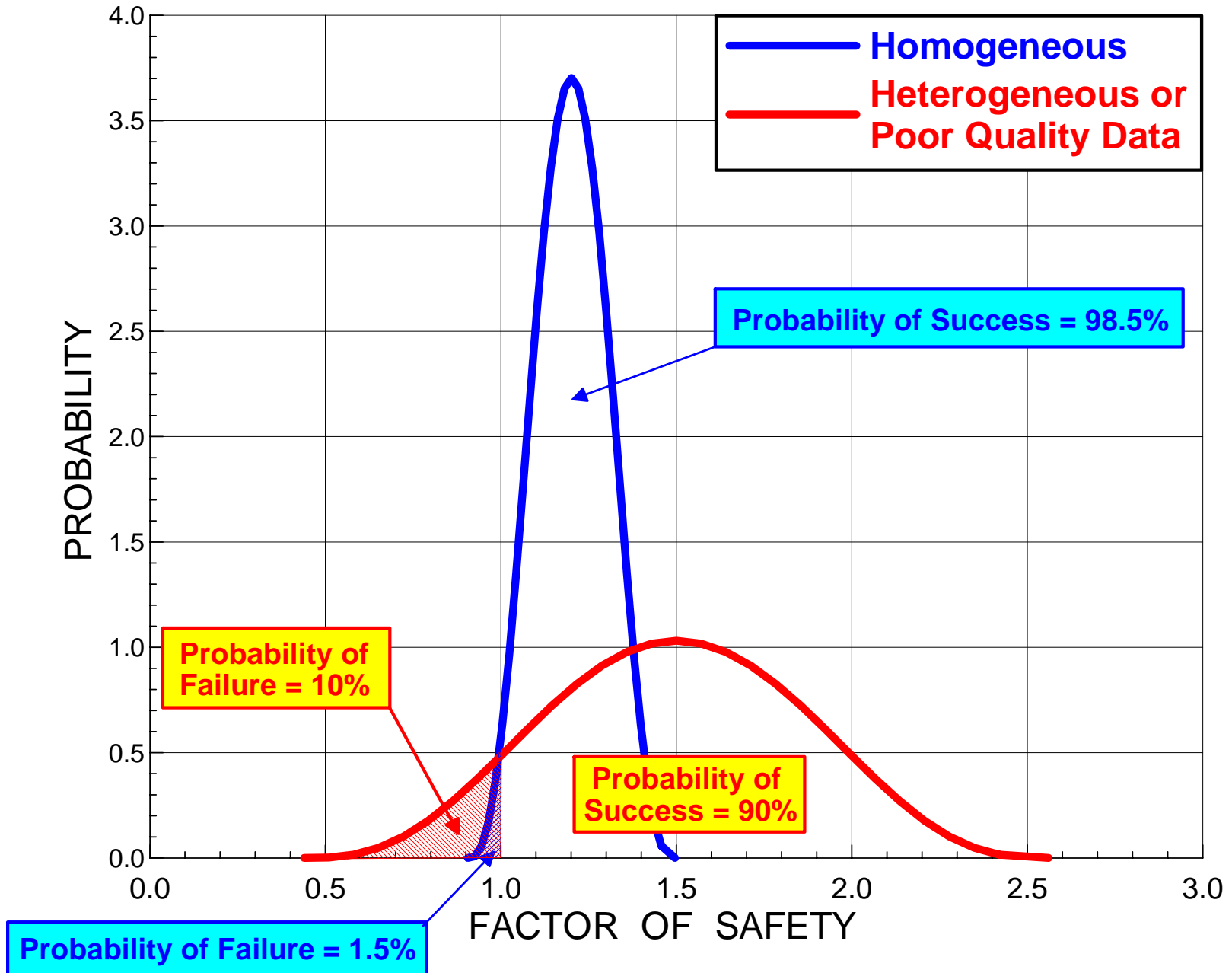
Calculating Risk—Probability

- ◆ For settlement analysis; y-axis is probability & x-axis is settlement
- ◆ For slope stability analysis; y-axis is probability & x-axis is factor of safety
- ◆ For pile analysis; y-axis is probability & x-axis is column load & pile capacity
- ◆ Satisfactory Performance = The area under beta probability curve either below threshold value for settlement, above value of 1.0 for slope stability, where pile capacity exceeds column load

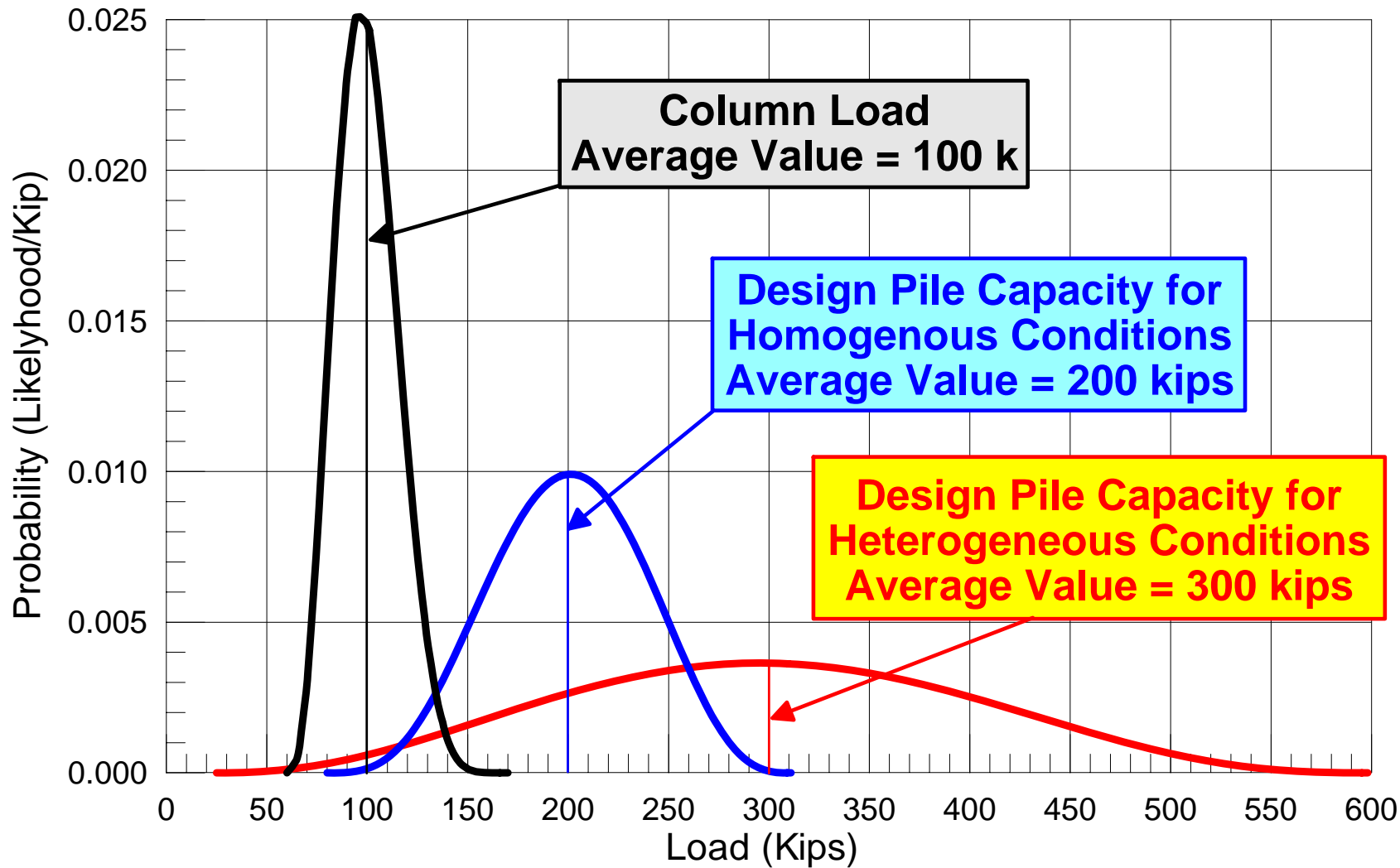
PROBABILITY ANALYSIS FOR SETTLEMENT



PROBABILITY ANALYSIS FOR SLOPE STABILITY



PROBABILITY ANALYSIS OF PILES





Calculating Risk (Cont.)

- ◆ Area under the entire curve must be 1.00
[Definition of Probability]
- ◆ Trapezoidal method to compute area is sufficiently accurate when widths are small
- ◆ It is easier to compute triangular failure area first, then probability of success is 1.0 minus that area



Owner Benefits



- ◆ Most economical design can be chosen at an acceptable risk level to owner
- ◆ Accurate site characterization program reduces uncertainty and minimizes costly contractor change orders including differing subsurface conditions



Conclusions



- ◆ Focus on variability of subsurface conditions by minimizing variability from test error
- ◆ Select tests that accurately predict soil properties
- ◆ Design to satisfy risk criteria acceptable to owner
- ◆ Designs will be less conservative for homogeneous conditions (less uncertainty) than for heterogeneous conditions



Concluding Quote

- ◆ The professional must, under all circumstances, give maximum caliber service.
- ◆ The nonprofessional can dilute the quality of his commodity or service to fit the size of the client's fee; not so the professional.
 - (Bachner, 1991)