



SPT? – A better approach to site  
characterization of residual soils using  
other In-Situ tests

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GOOD DATA +  
GOOD ENGINEERING =  
GOOD DESIGN



# Site Characterization Objectives

- ◆ Quantify soil properties
- ◆ Chosen tests must measure or model property of interest
- ◆ Assess variability of properties
- ◆ Minimize parasitic test variability
- ◆ 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 residual soil formations
- ◆ Adequate when there is really only one practical engineering design solution



# SPT Disadvantages

- ◆ Remolds soil and destroys important latent rock structure in residual soil
- ◆ Commonly performed at 1.5m intervals
- ◆ Dynamic test—does not measure static properties
- ◆ Energy rarely calibrated—can vary by a magnitude of 3



# SPT-The Big Guess!



- ◆ Test error causes high uncertainty—can lead to overly conservative and very costly designs



# Pressuremeter Test

- ◆ Calibrated static deformation test
- ◆ Requires high quality undisturbed borehole
- ◆ Test interval  $\Rightarrow$  1.5 meter
- ◆ Can test rock



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# Electric Cone Penetration Test

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- ◆ 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

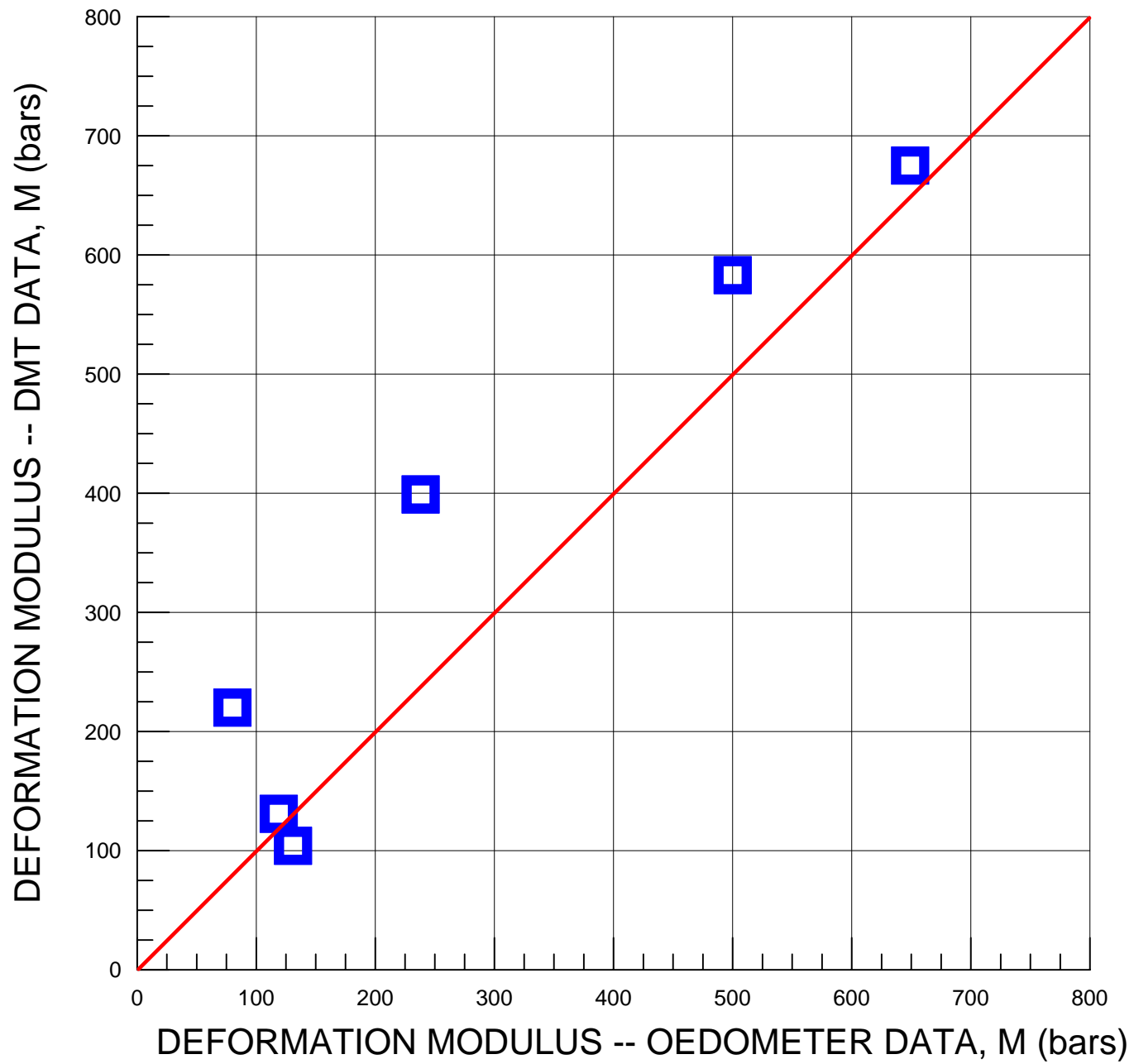


# Dilatometer Test

- ◆ 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 and latent rock structure
- ◆ 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 →





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# Borehole Shear Test

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



# 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.



# Quantifying Risk

- ◆ With good quality data, the engineer can quantify 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
- ◆ 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
- ◆ From owner's viewpoint, if the engineer does not discuss risk—they assume all the risk

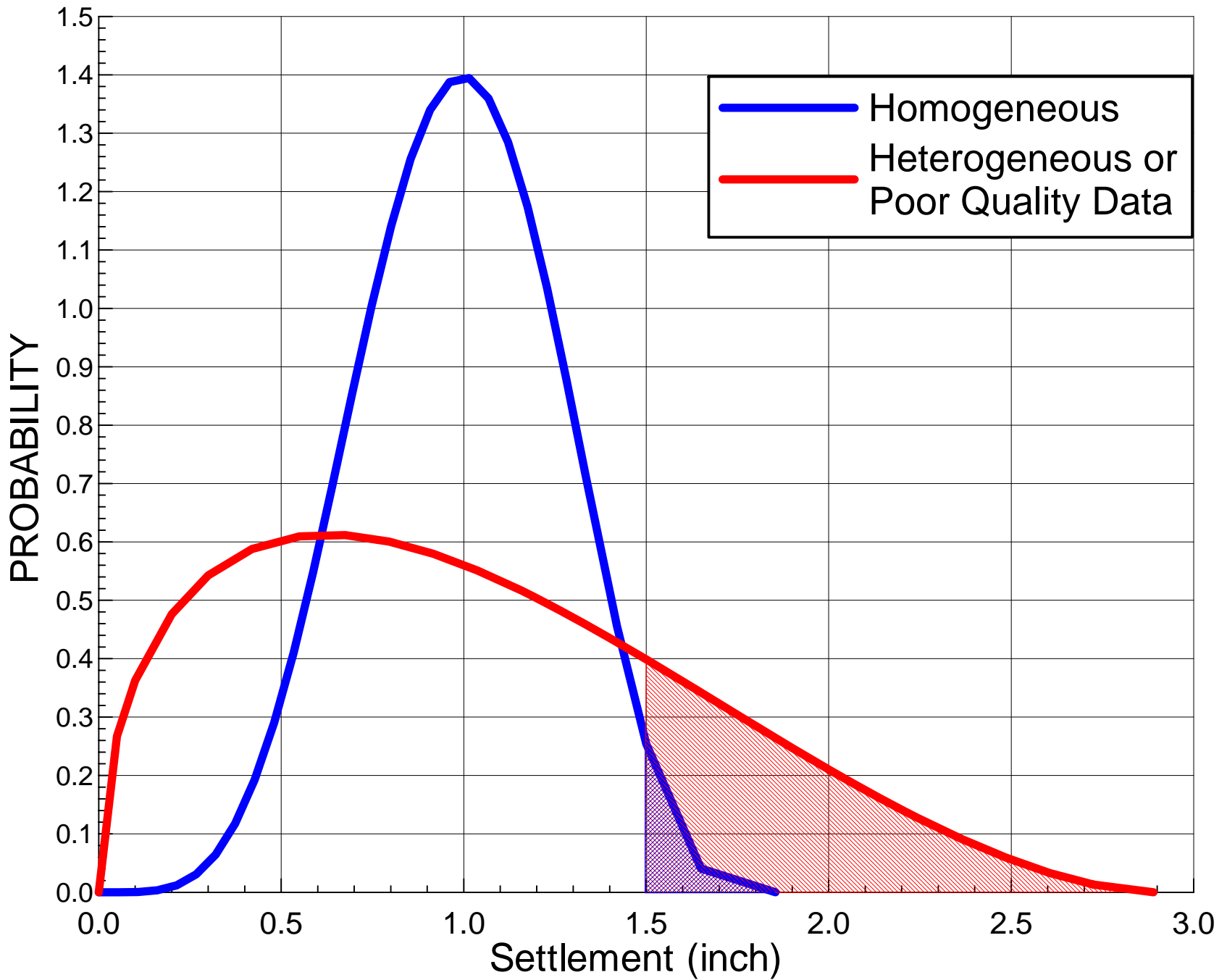


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# Probability Approach Advantages

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- ◆ Evaluates the risk of exceeding a threshold limit—tail ends of probability curve
- ◆ Normal probability function ranges from negative infinity to positive infinity
- ◆ Log normal probability function ranges from zero to positive infinity
- ◆ Beta probability function—minimum and maximum values are chosen by the engineer





# Beta Probability Function



- ◆ Formulas given in paper—engineer must determine average, standard deviation, minimum and maximum values as input
- ◆ Spreadsheet can quickly perform computations
- ◆ Beta function formula can be checked—area under curve must equal 1.0



# Calculating Risk

- ◆ 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
- ◆ Satisfactory Performance = The area under beta curve either below threshold value for settlement or above value of 1.0 for slope stability



## Calculating Risk (Cont.)



- ◆ 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



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# Settlement Probability Design

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- ◆ Standard deviation is a combination of three variables, assumed to be independent
  - Site or project spatial variability
  - Test and design method variability
  - Intangible or other variability

# Settlement Probability (cont.)

1) What is spatial variability of soil properties over project site?

Ans.=>Collect enough good quality data

2) How well test and design methods predict field performance?

Ans.=>Use case study data to determine average and standard deviation values of the predicted-to-measured ratio [avg ~ 1.0; low S.D.]



# DMT Method Procedure



- ◆ Predict settlement from each sounding—each prediction becomes data point
- ◆ Compute average and standard deviation (project spatial) from data set
- ◆ Correct values by dividing by measurement bias (avg. Predicted/Measured value)

## DMT Procedure (cont.)

- ◆ From Schmertmann (1986) case study data; average predicted-to-measured ratio = 1.18 and standard deviation = 0.38
- ◆ Excluding driving DMT blade and quick clayey silts; Avg = 1.07 & S.D. = 0.22
- ◆ Method's coefficient of variation = 32% for all cases and 21% excluding special cases
- ◆ Compute method deviation by multiplying C. of V. (0.21 or 0.32) by corrected average value

## Method Procedure (cont.)

- ◆ Compute other intangible deviation by multiplying its C. of V. by corr. Avg. value
- ◆ Overall standard deviation = square root of  $\{(\text{proj dev.})^2 + (\text{meth dev})^2 + (\text{other dev})^2\}$
- ◆ Determine minimum and maximum values [Harr suggests +/- 3 standard deviations]
- ◆ Compute beta probability function



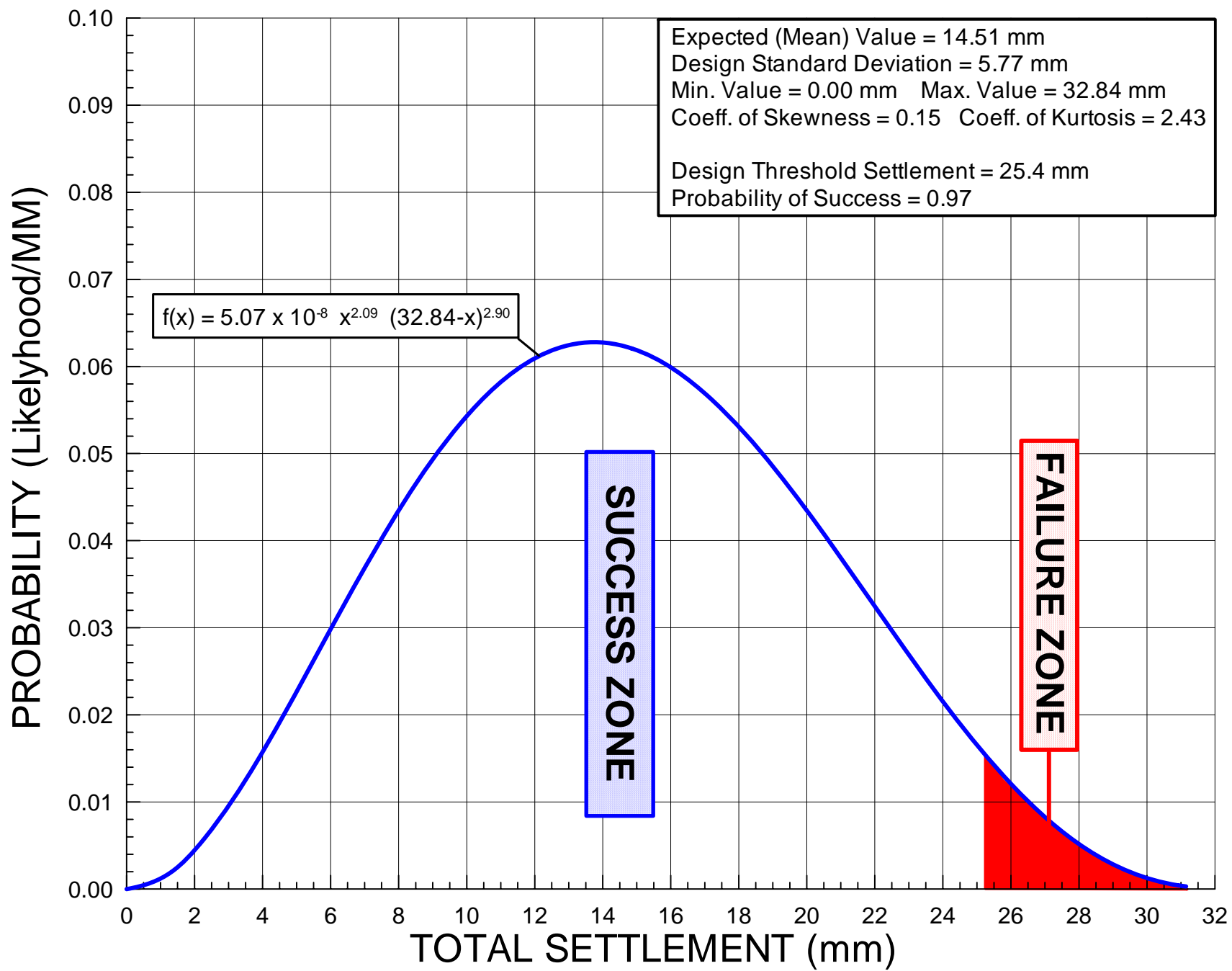
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## Method Procedure (cont.)

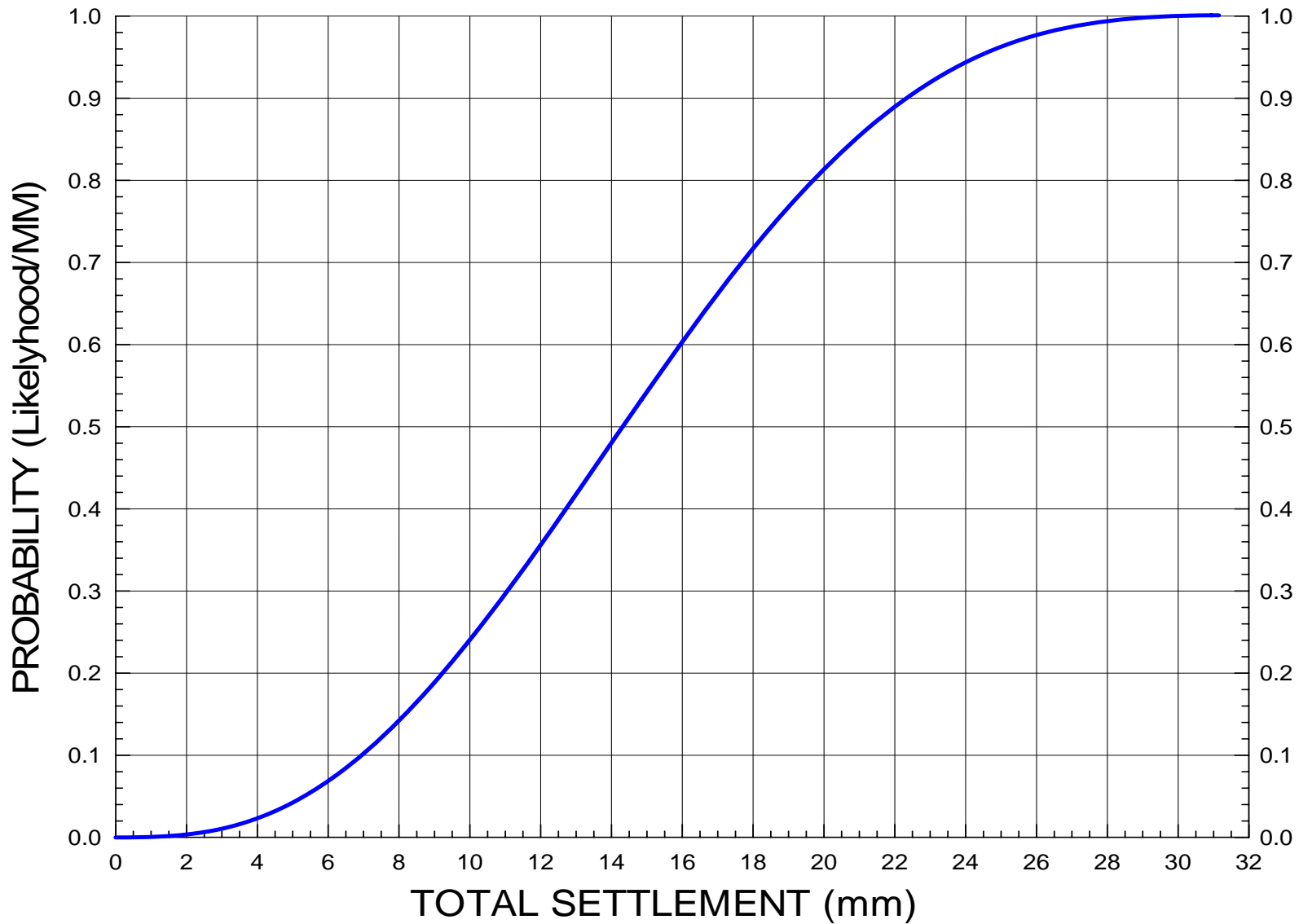
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- ◆ Use trapezoidal method and check if formula is correct—area must equal 1.0
- ◆ Compute triangular area above chosen threshold settlement—probability of failure
- ◆ Compute probability of success =  $1.0 -$  probability of failure

# BETA PROBABILITY DISTRIBUTION FUNCTION



# BETA CUMULATIVE DISTRIBUTION FUNCTION





# Slope Stability Probability Design

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- ◆ Determine parameters that may vary & compute their average and standard deviation values
- ◆ Run stability trials using average value either plus or minus one standard deviation (Christian, 1997)
- ◆ There will be  $2^n$  combinations, where n is the number of variables
- ◆ Critical variables easily determined



# Slope Stability Shear Strength Parameters

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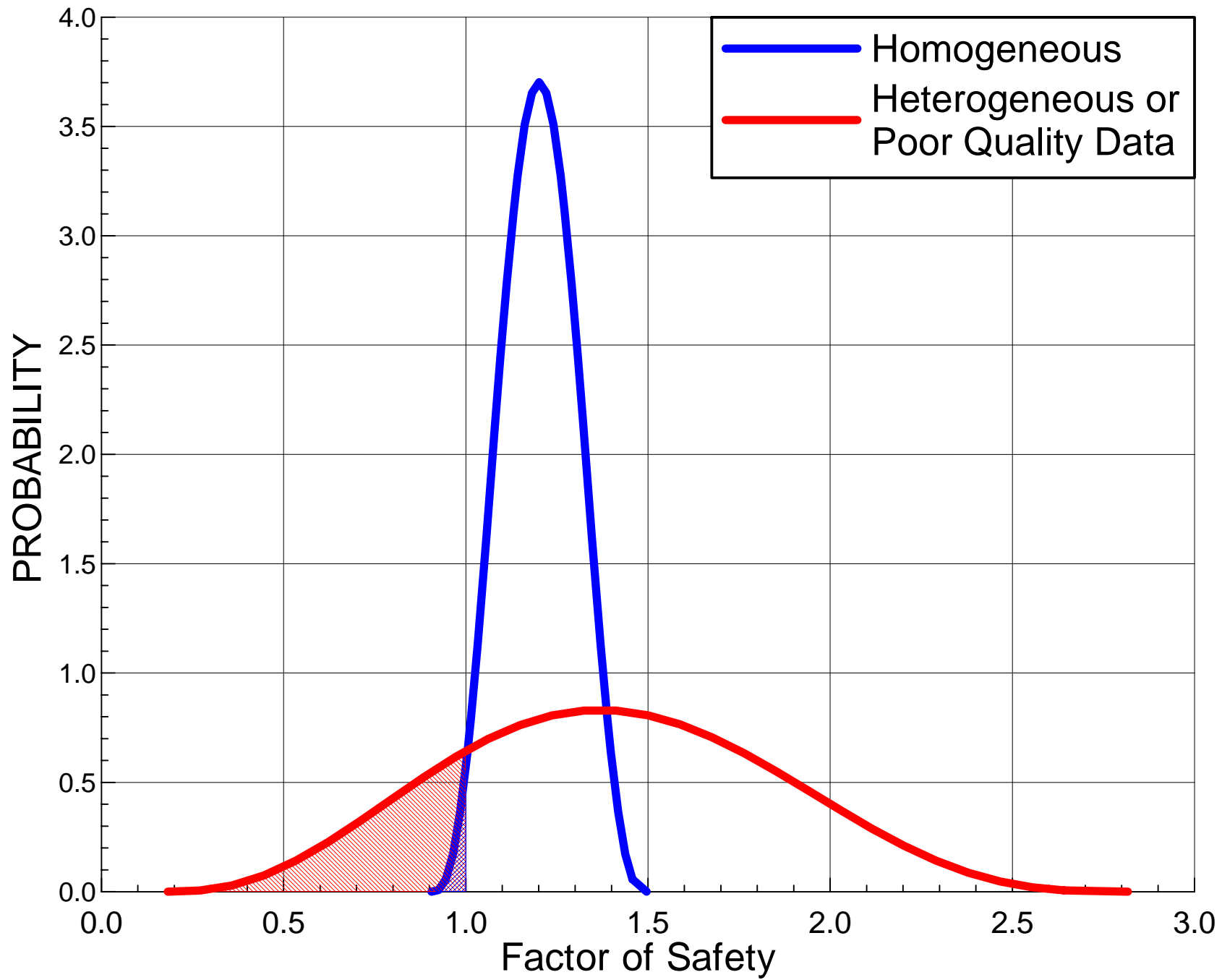
- ◆ Use either laboratory shear strength tests or insitu dilatometer/piezocone (undrained conditions) or borehole shear tests (drained conditions)
- ◆ Advantage of insitu tests is that many more can be conducted than lab tests within same budget—more data to determine average and standard deviation values

# Stability Probability Design (cont.)

- ◆ Minimum F.S. from each analysis becomes a data point for creating beta probability function
- ◆ Compute average and standard deviation from that data set
- ◆ Choose minimum & maximum values for beta probability curve

# Stability Probability Design (cont.)

- ◆ Calculate beta probability function, with X-axis being factor of safety
- ◆ Check that area under beta probability function = 1.0
- ◆ Probability of success = area under beta probability function that exceeds a F.S. of 1.0





# 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 and minimize test variability
- ◆ 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