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Addressing Uncertainties in Design Inputs: A Case Study of Probabilistic Settlement Evaluations for Soft Zone Collapse at SWPF

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Introduction

- Description of the SWPF Settlement Problem
- Deterministic v. Probabilistic Approach to Settlement Profile Development
- Analysis Approach
- Parameters considered
- Methodology
- Results synthesis
- Why the approach was useful

Description of the SWPF Settlement Problem

- At SRS, post-seismic differential settlement is caused by the potential collapse of soft zones
- Large uncertainty in the geotechnical parameters defining size of soft zones and associated surface expression
- Even more uncertainty in the location of potential settled region because soft zones between borings cannot be precluded
- A probabilistic treatment of soft zone size and location was performed to determine the probabilistic distribution of building demands
- Probabilistic results were used to assess the conservatism of results obtained from use of a subset of deterministic profiles

Deterministic v. Probabilistic Approach to Settlement Profile Development

- Geotechnical parameters used in settlement profile development
  - Soft zone location and depth
  - Thickness and shape of the soft zone
  - Beta angle
  - Consolidation strain
  - Subgrade modulus
- Deterministic approach uses “conservative” estimates of the parameters
- Probabilistic approach uses probabilistic estimates of the expected values and range of parameters

Advantages of Probabilistic Approach

- Permits identification of parameters having significant influence on structural demands
- Parameters having significant influence on design can be subject to more scrutiny than less influential parameters
- Permits the development of estimates of margin against the facility not performing it required function → can be used to justify whether a facility meets DOE-STD-1020

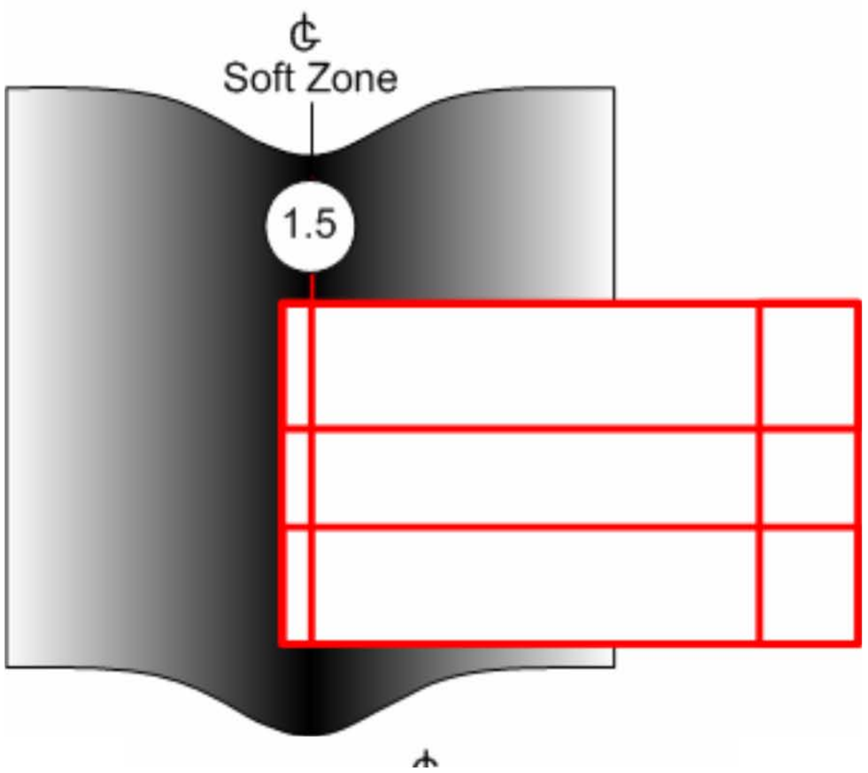
Analysis Approach

- Evaluation of building response given a settlement profile
  - Standard FE methods
- Evaluation of a series of deterministic profiles
  - Limited set of profiles allows for a more easily implemented design process
- Evaluation of a series of probabilistically generated settlement profiles
  - Large number of profiles (10,000+)
- Synthesis of probabilistic and deterministic results to determine appropriate design parameters

Parameters Considered

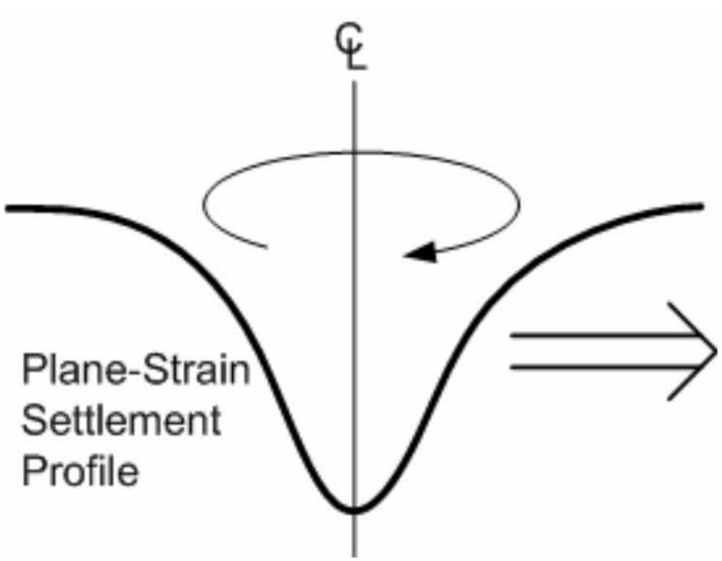
- Configuration of the consolidated soft zone for each soft zone region
  - Either plane strain (2D) or axisymmetric (3D) settlement profile
- Number and location of soft zone regions
  - Local site data indicated likely soft zone regions
- Magnitude of consolidated strain
- Thickness, depth, and width of soft zone region
- Angle of draw (beta)
- Subgrade modulus

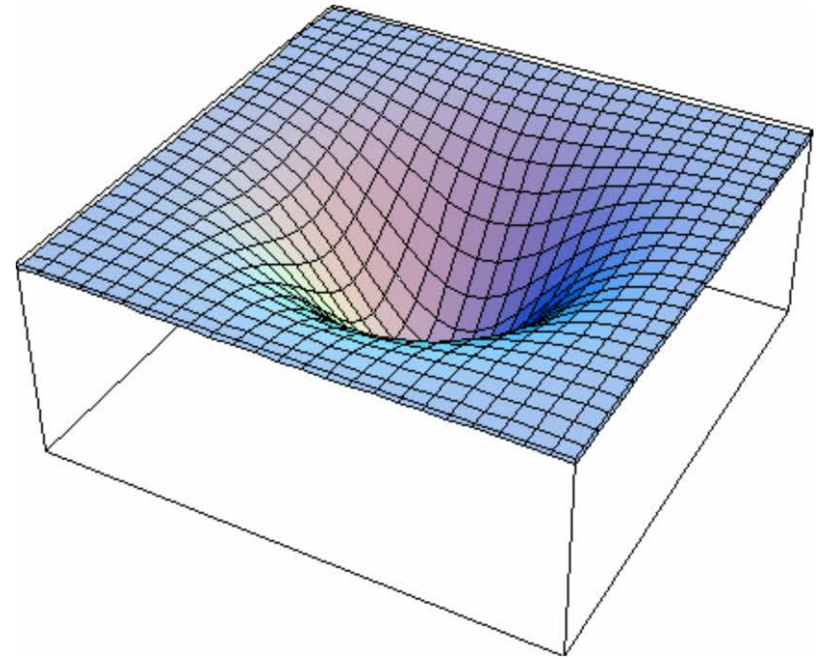
Plane Strain Profile (2D) Example



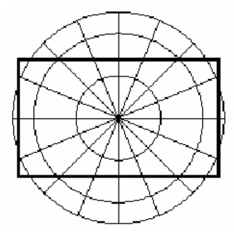
Grid Line 1.5

Axisymmetric (3D) Profiles

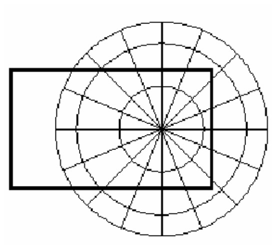




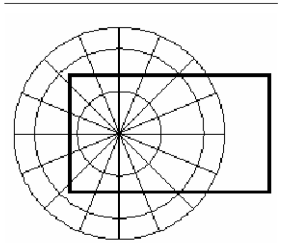
Axisymmetric (3D) Profiles



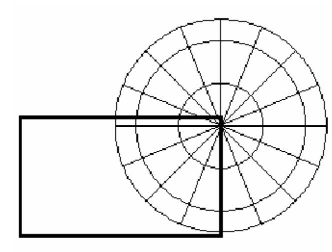
Center



East



West



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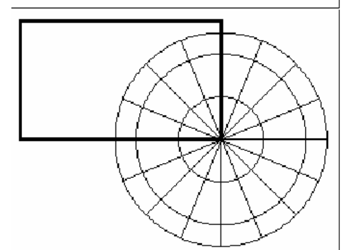
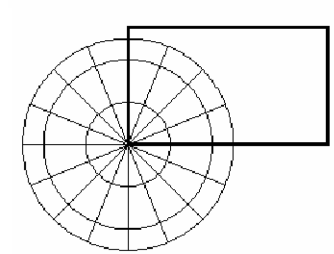
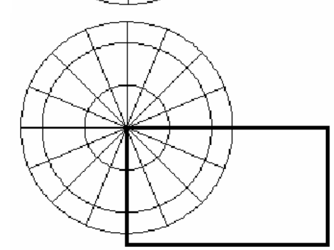


South East

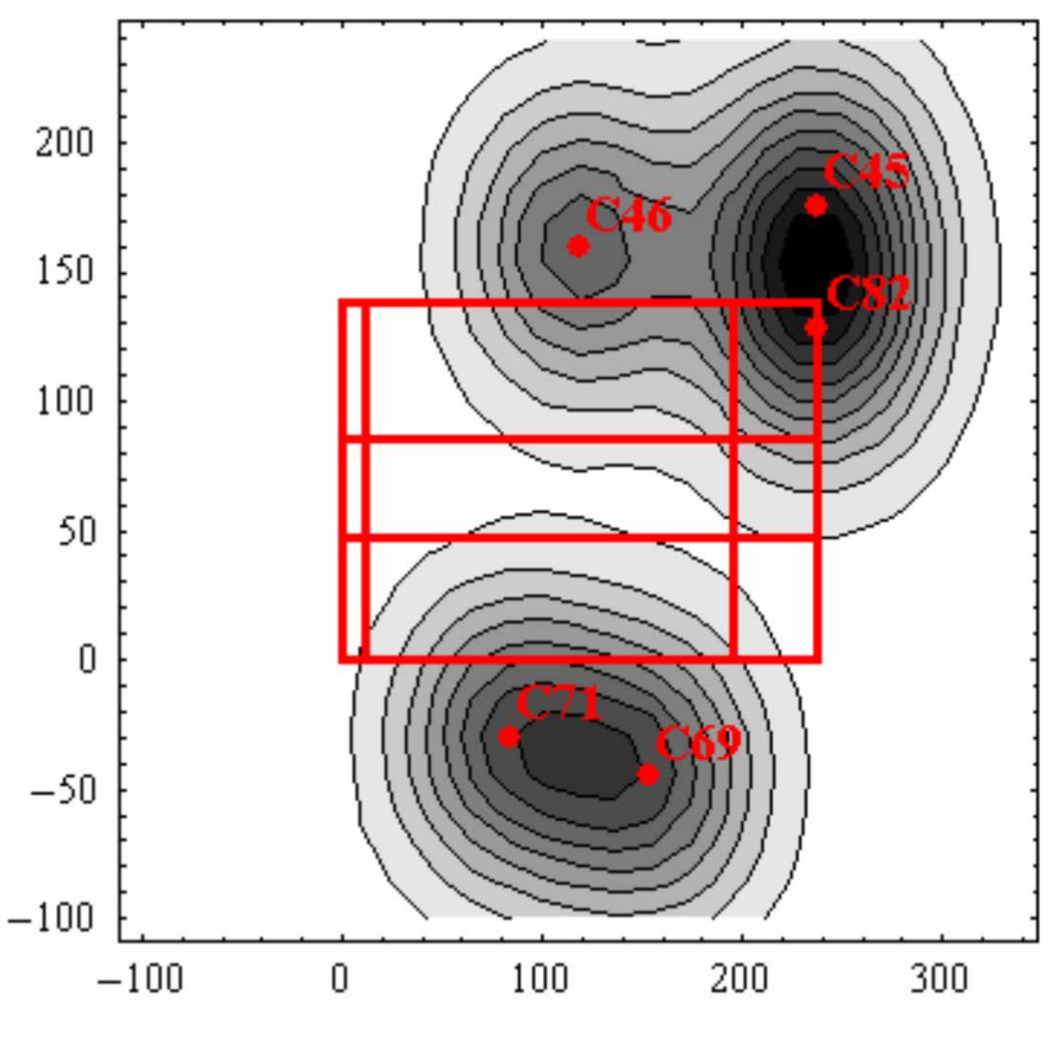


South West

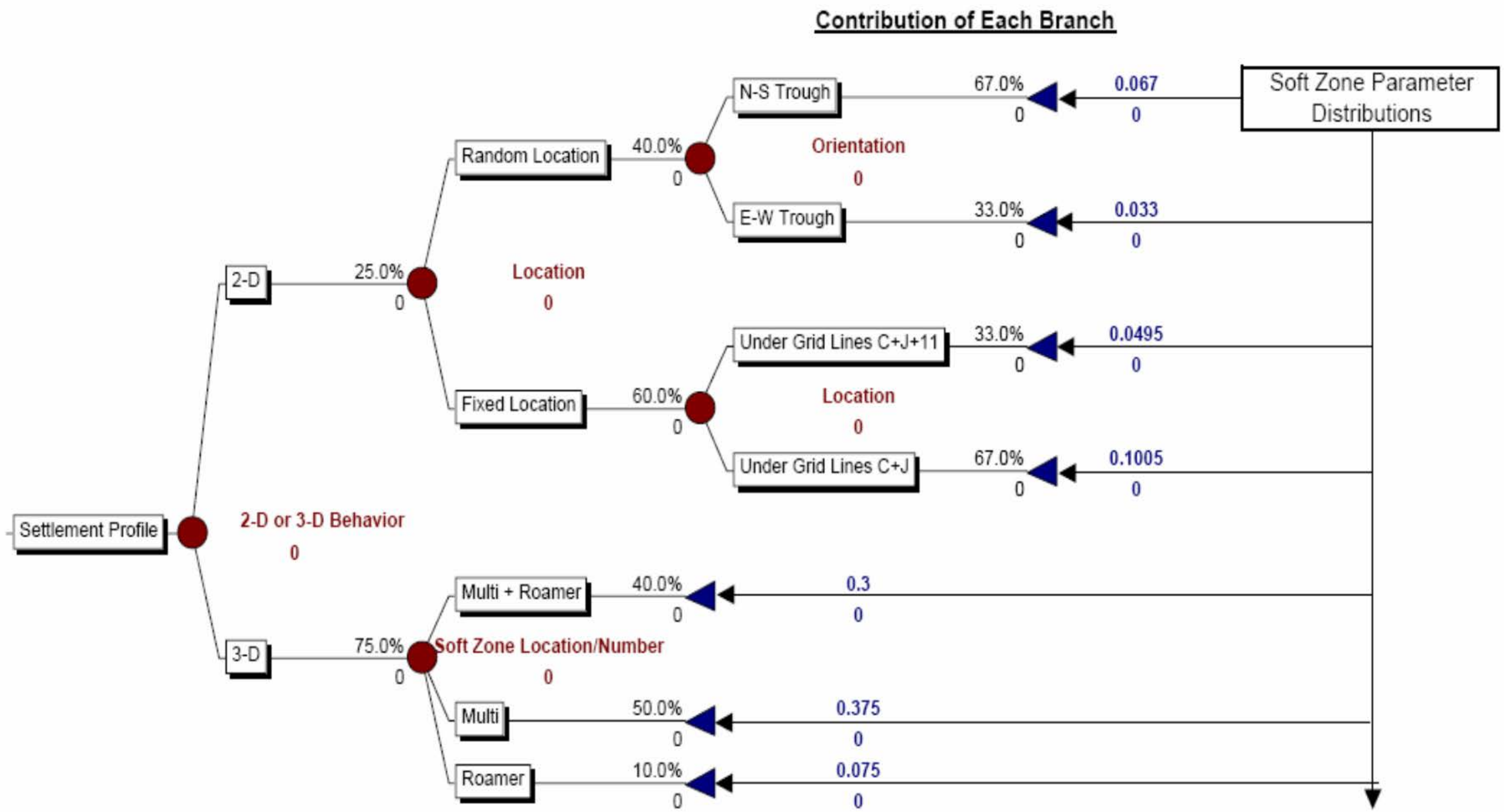


North West

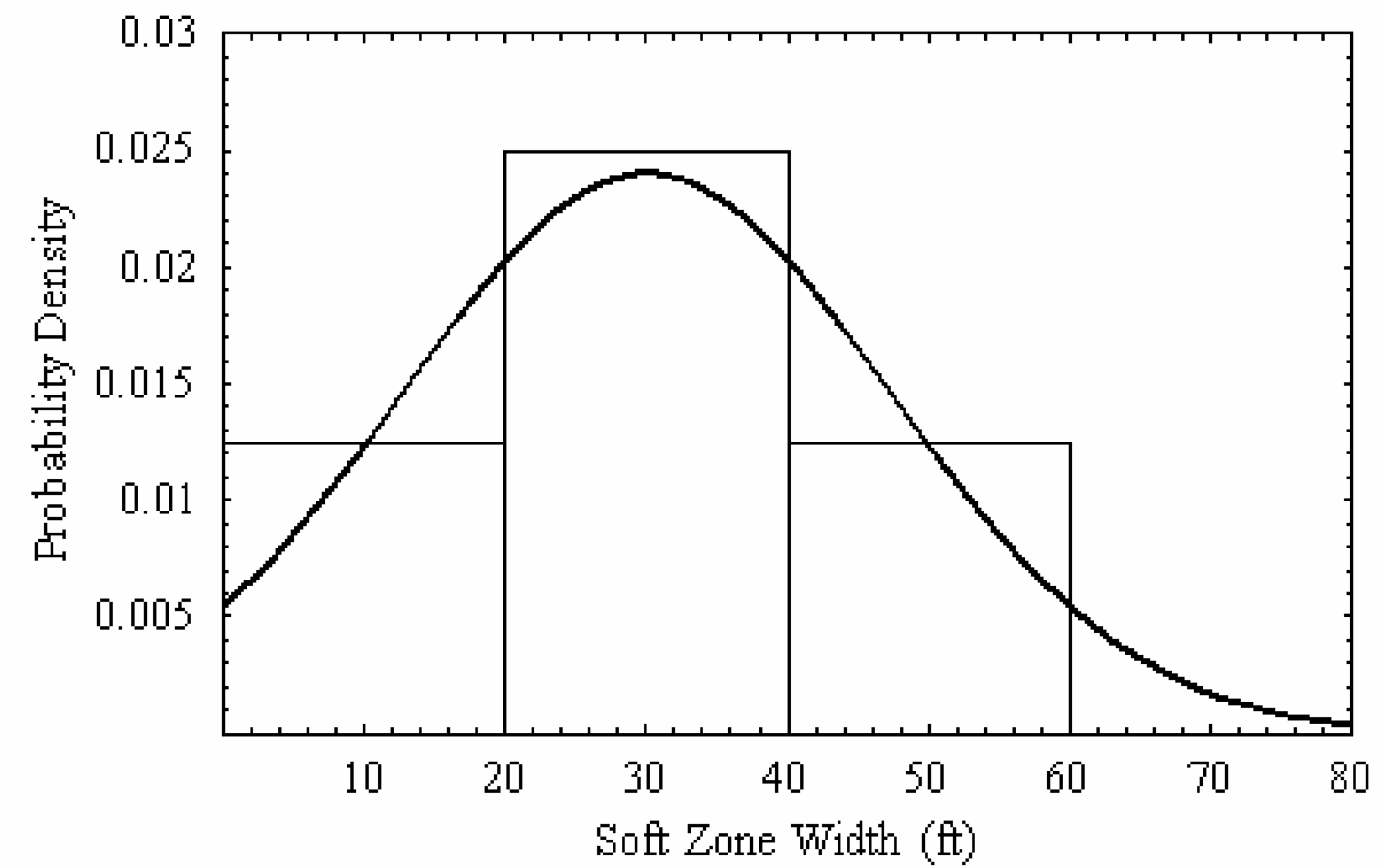
Combined Axisymmetric (3D) Profiles



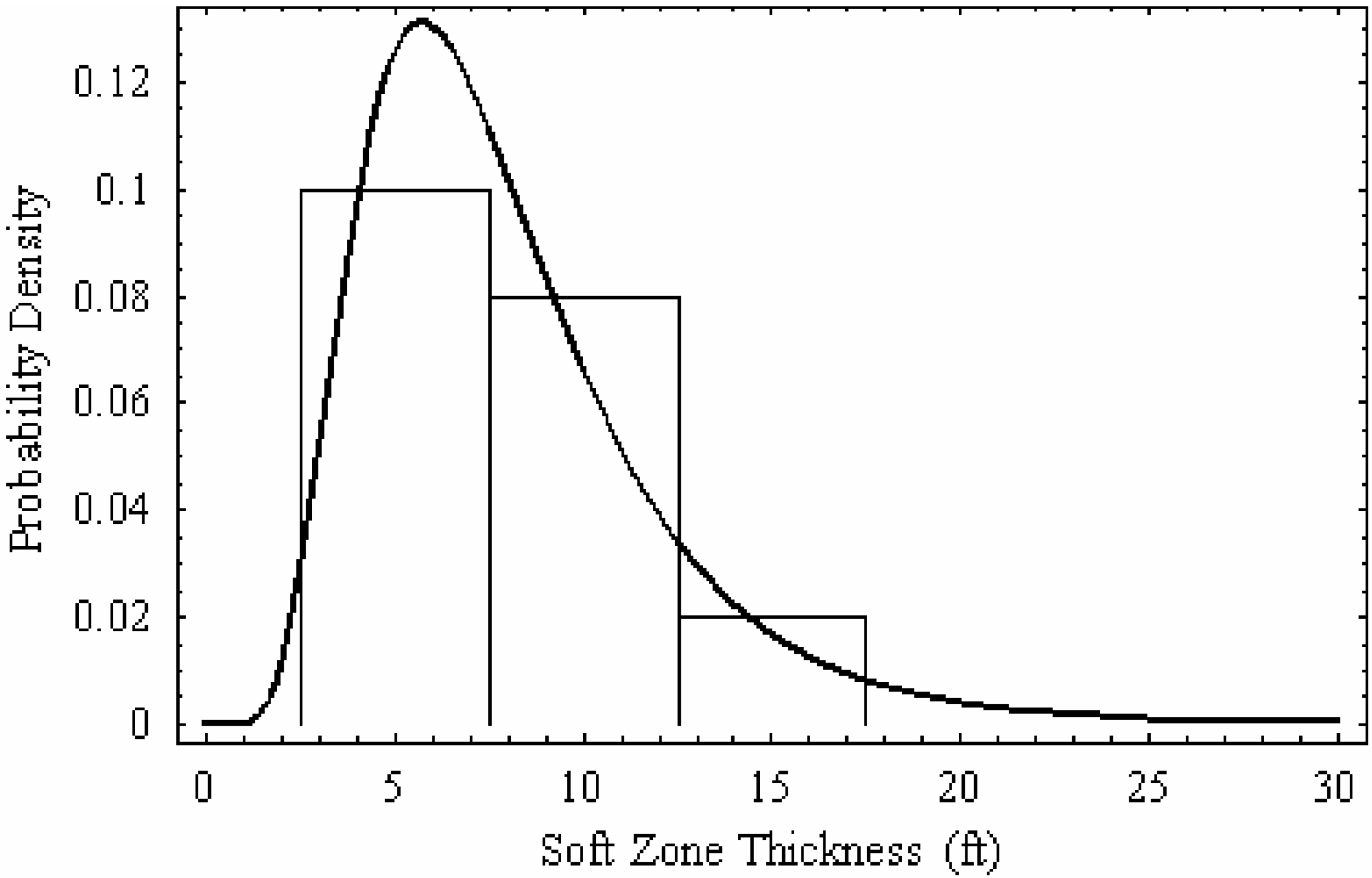
Logic Tree for Discrete Soft Zone Parameters



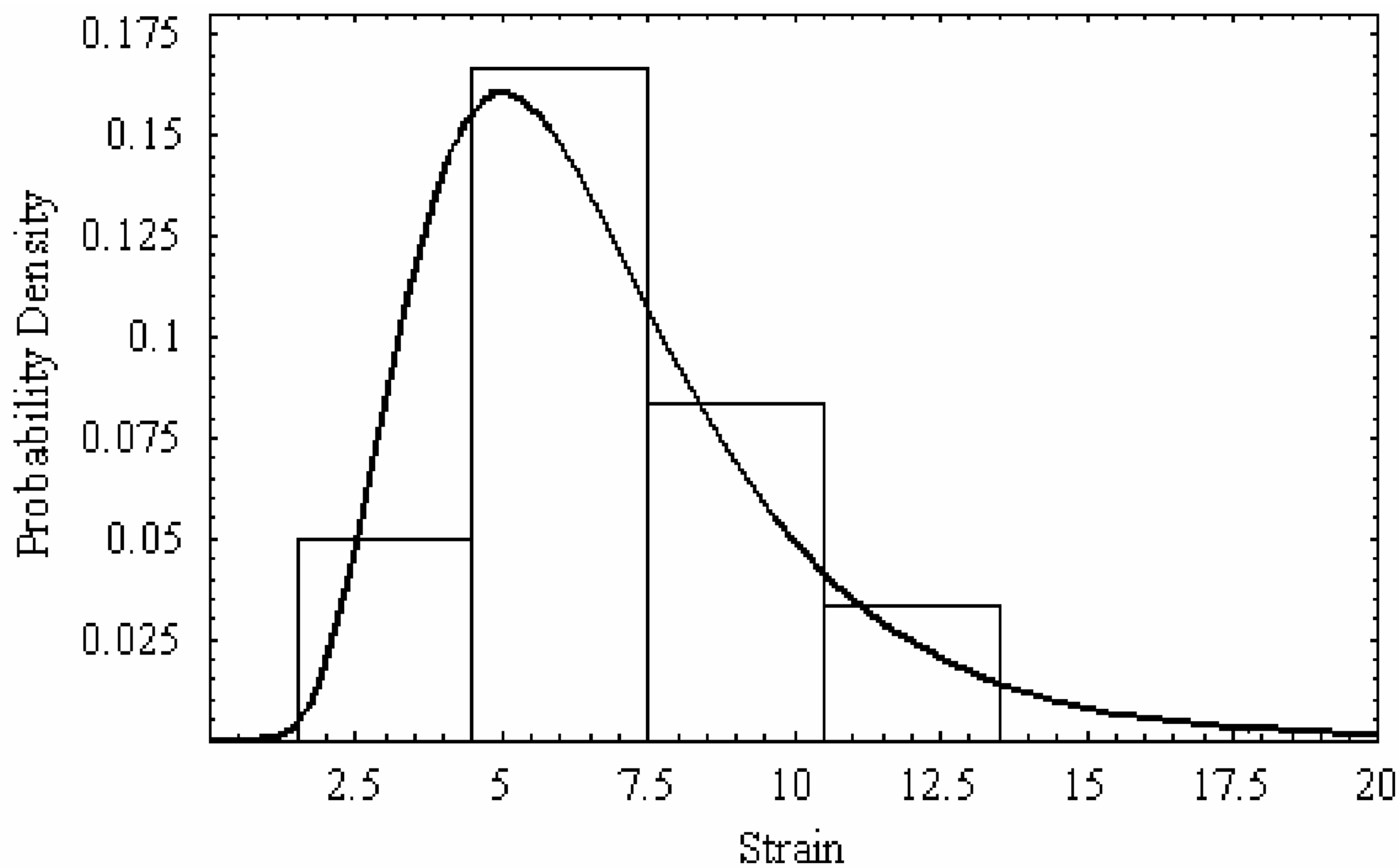
Probability Distribution of Soft Zone Width



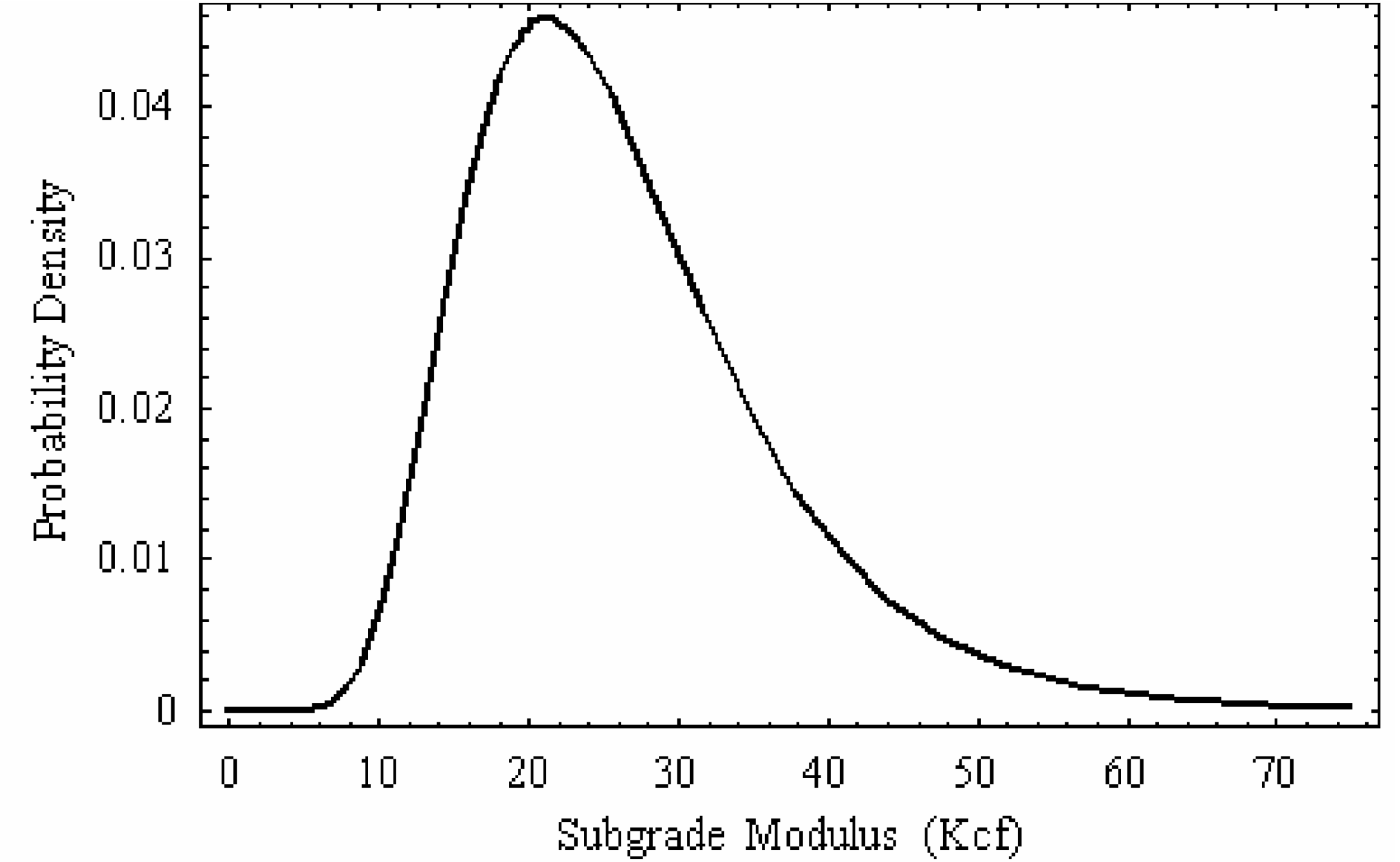
Probability Distribution of Soft Zone Thickness



Probability Distribution of Consolidated Strain



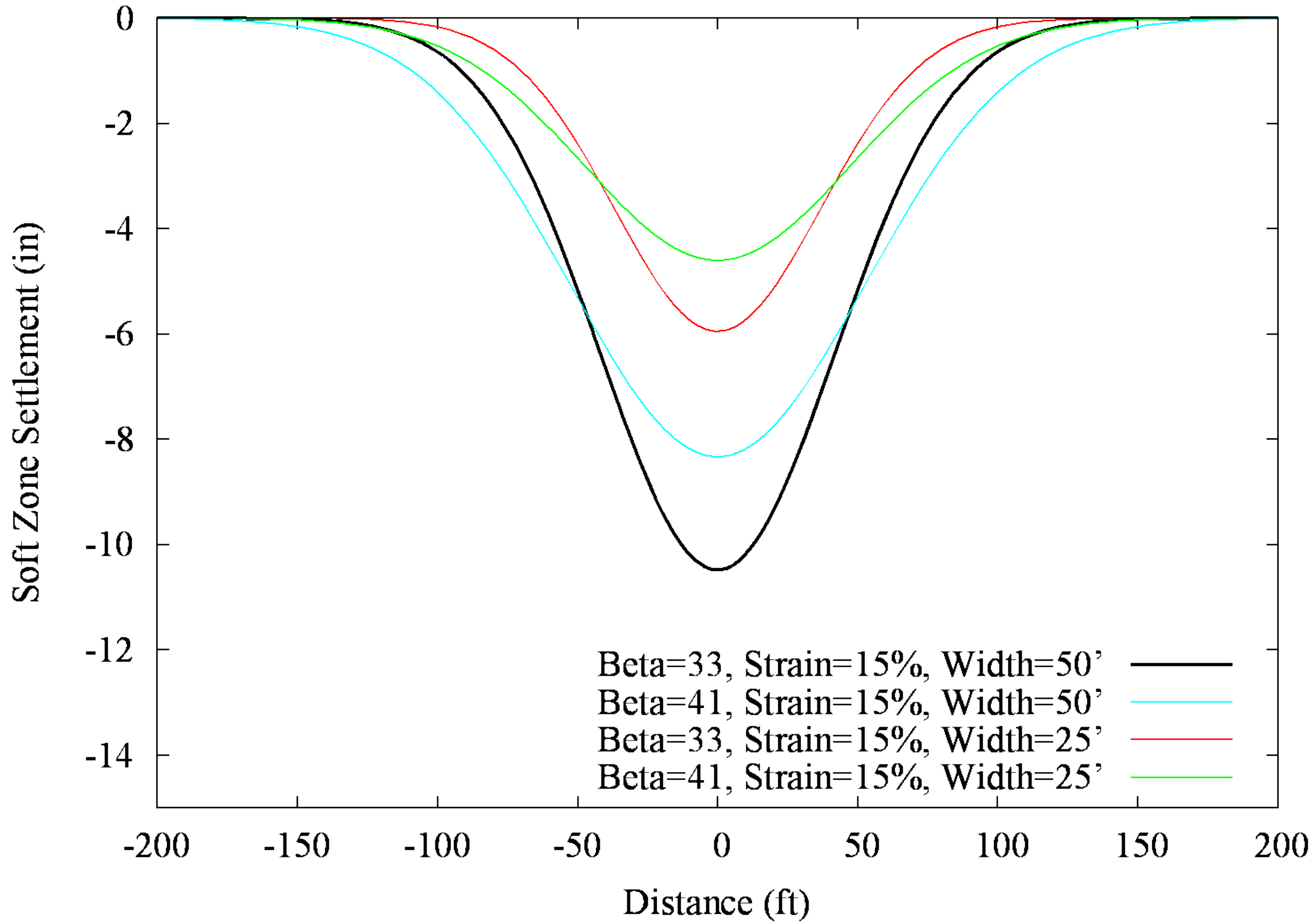
Probability Distribution of Subgrade Modulus



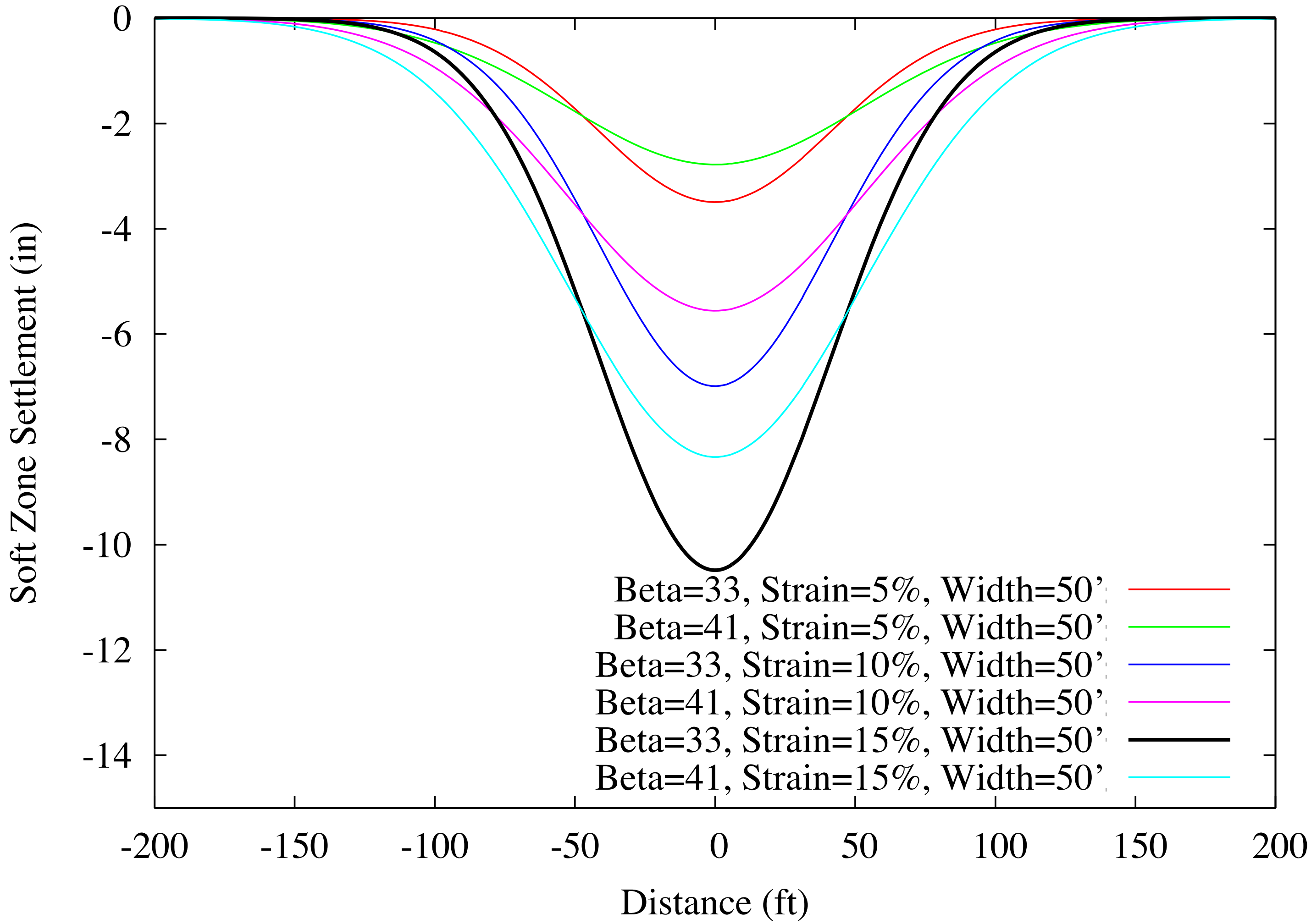
Probabilistic Analysis Methodology

- Uncertainties in parameters are incorporated into design through a combination of Monte Carlo Simulation and Logic Tree methods
- For a given set of parameters, building demands are computed
- Statistical synthesis of results to determine distribution of results

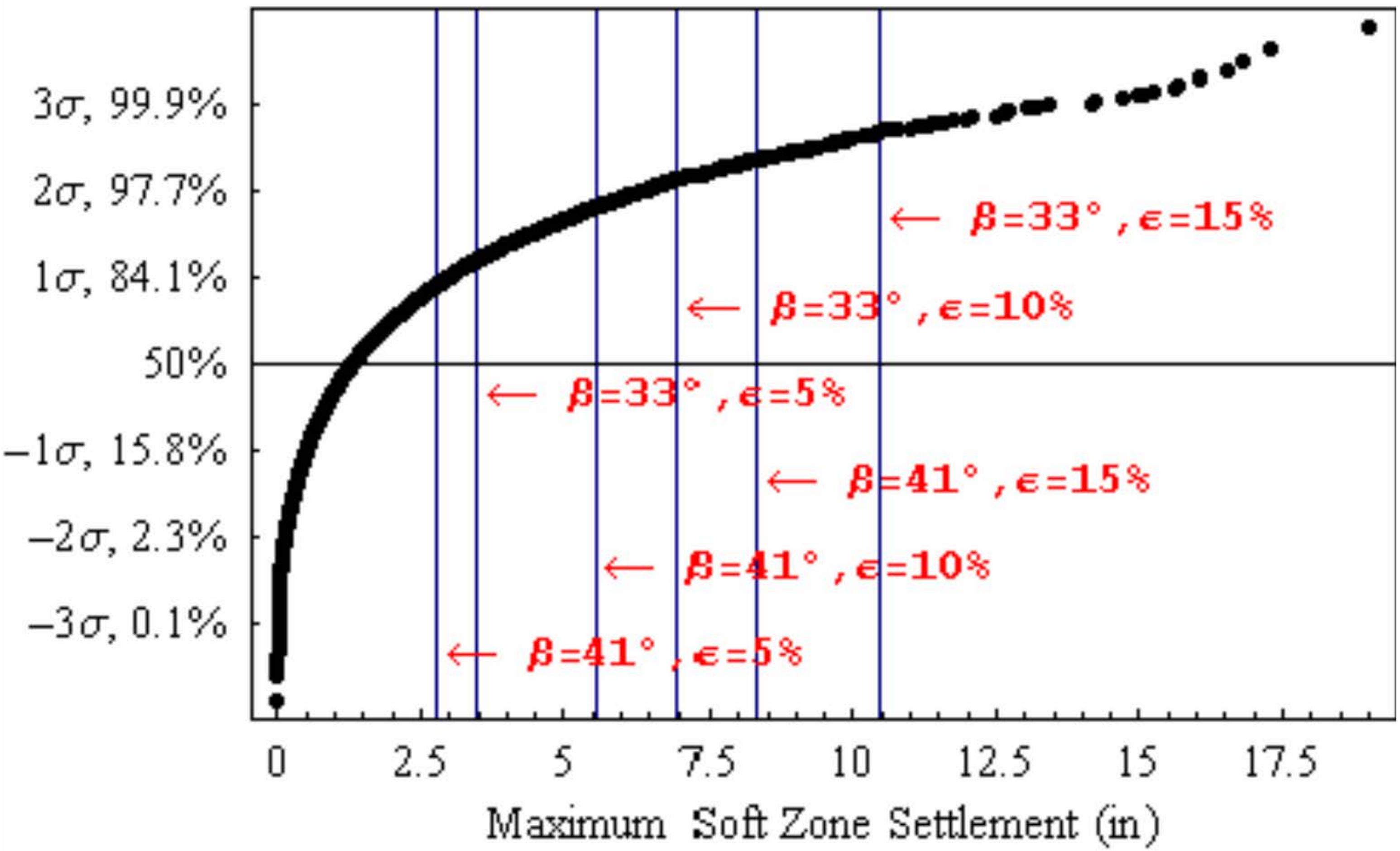
Plane Strain Settlement Profile for Various Soft Zone Widths



Plane Strain Settlement Profile for Various β Angles and Strain Levels



Comparison of Probabilistic and Deterministic Settlement Magnitudes

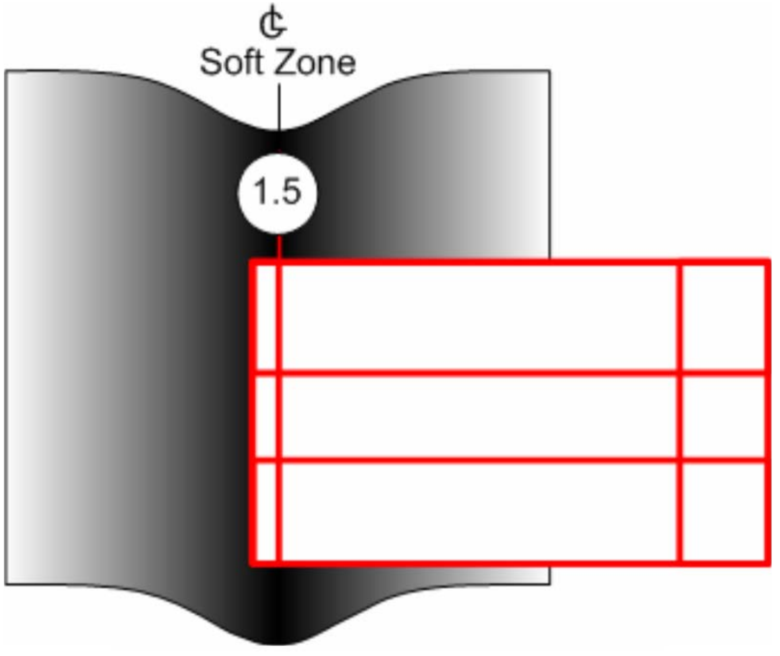


Results for a Deterministic Profile

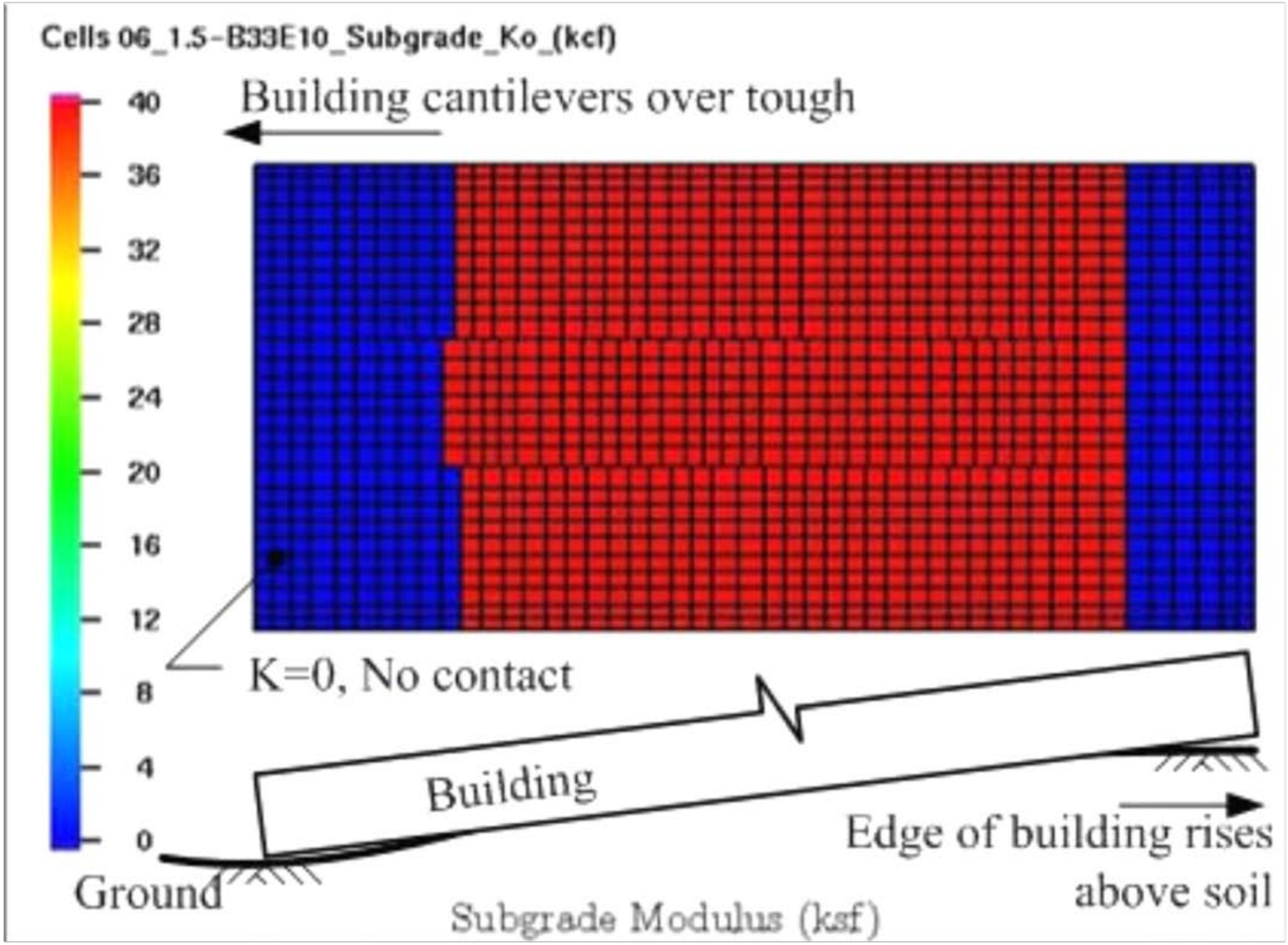
Parameters

- Plane Strain Settlement on Gridline 1.5
- $\beta = 33°$
- $\varepsilon = 10\%$
- Soft zone width = 50 ft
- Subgrade modulus = 40 kcf

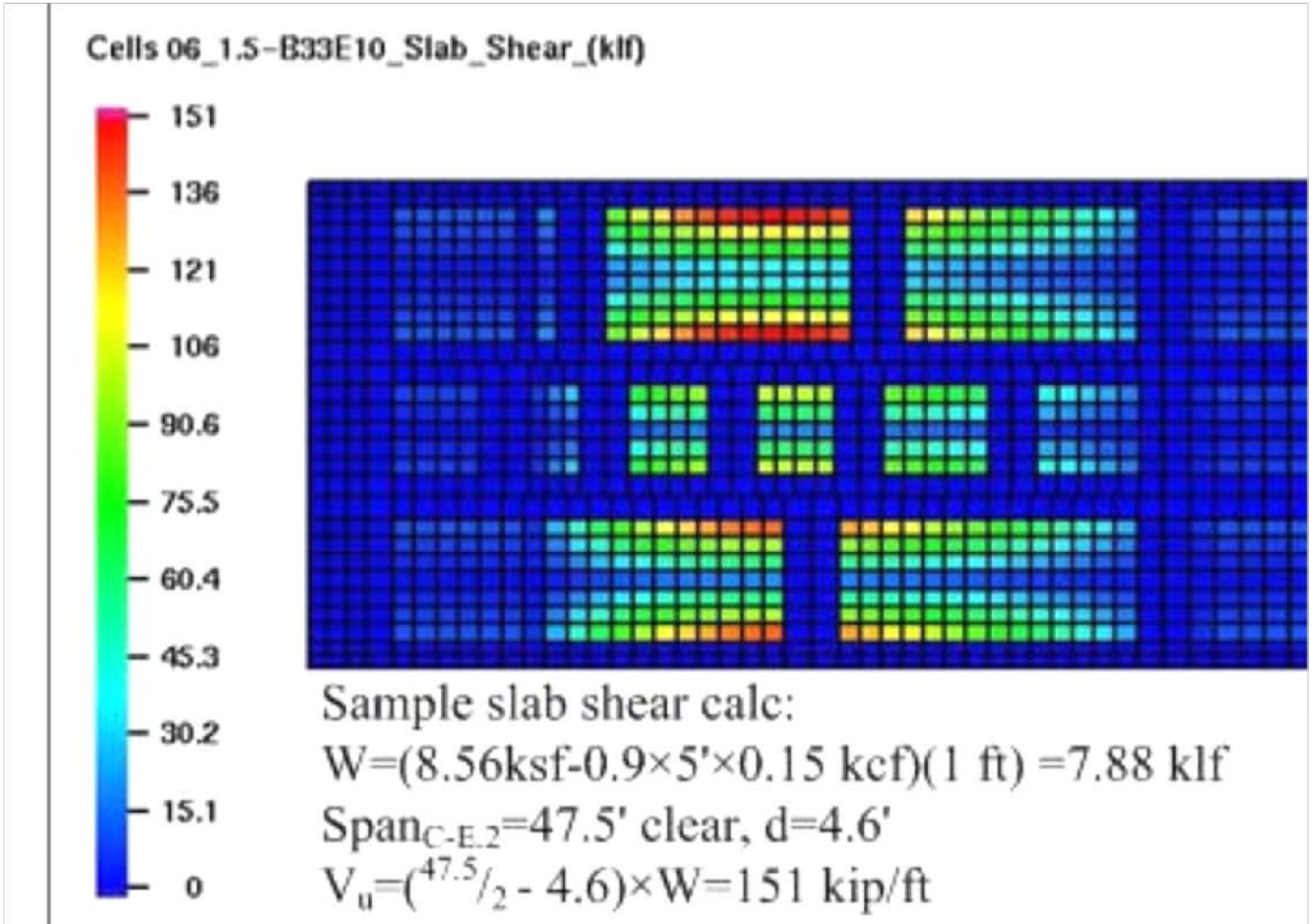
Settlement Location



Subgrade Modulus

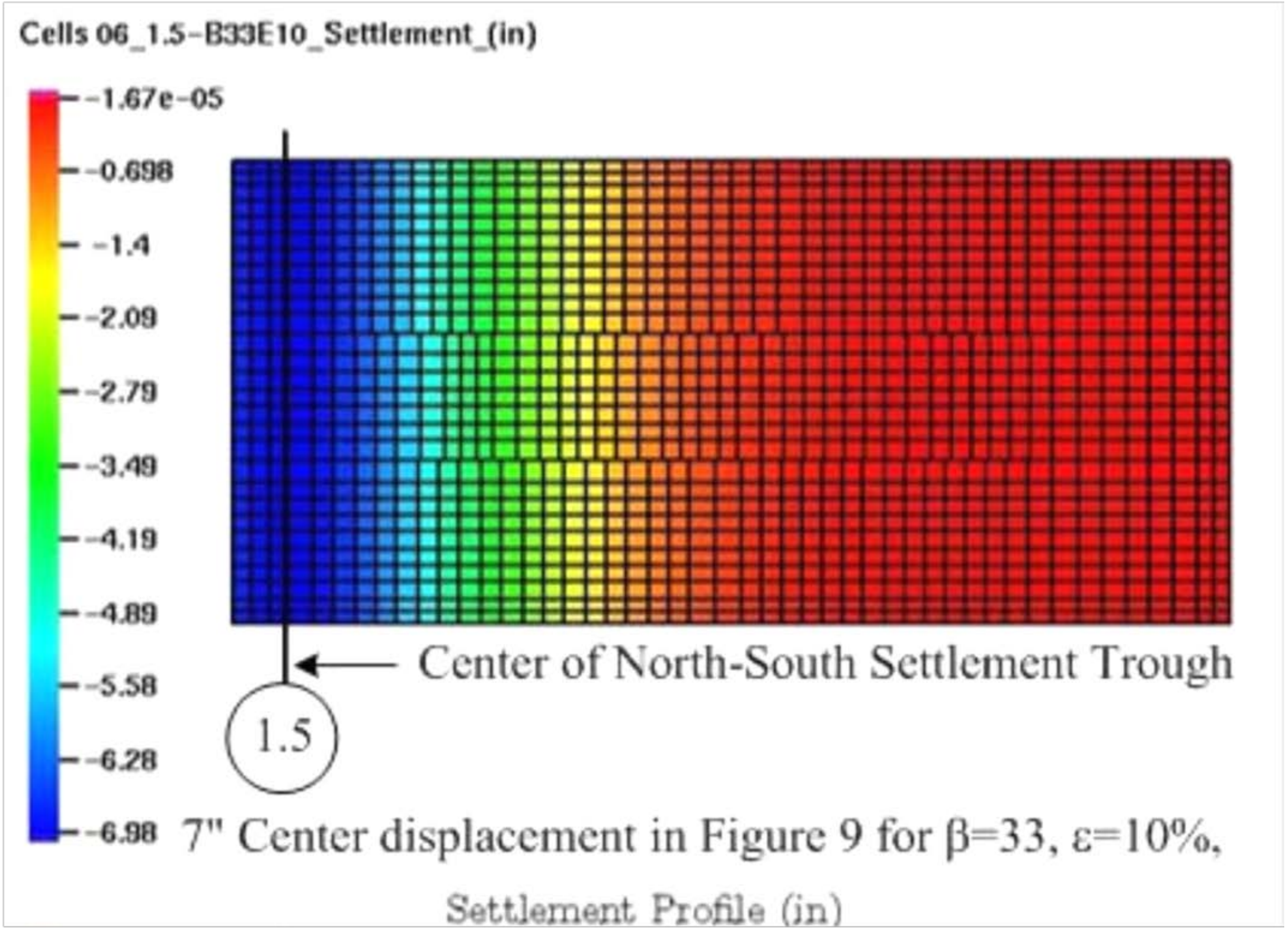


Slab Shear

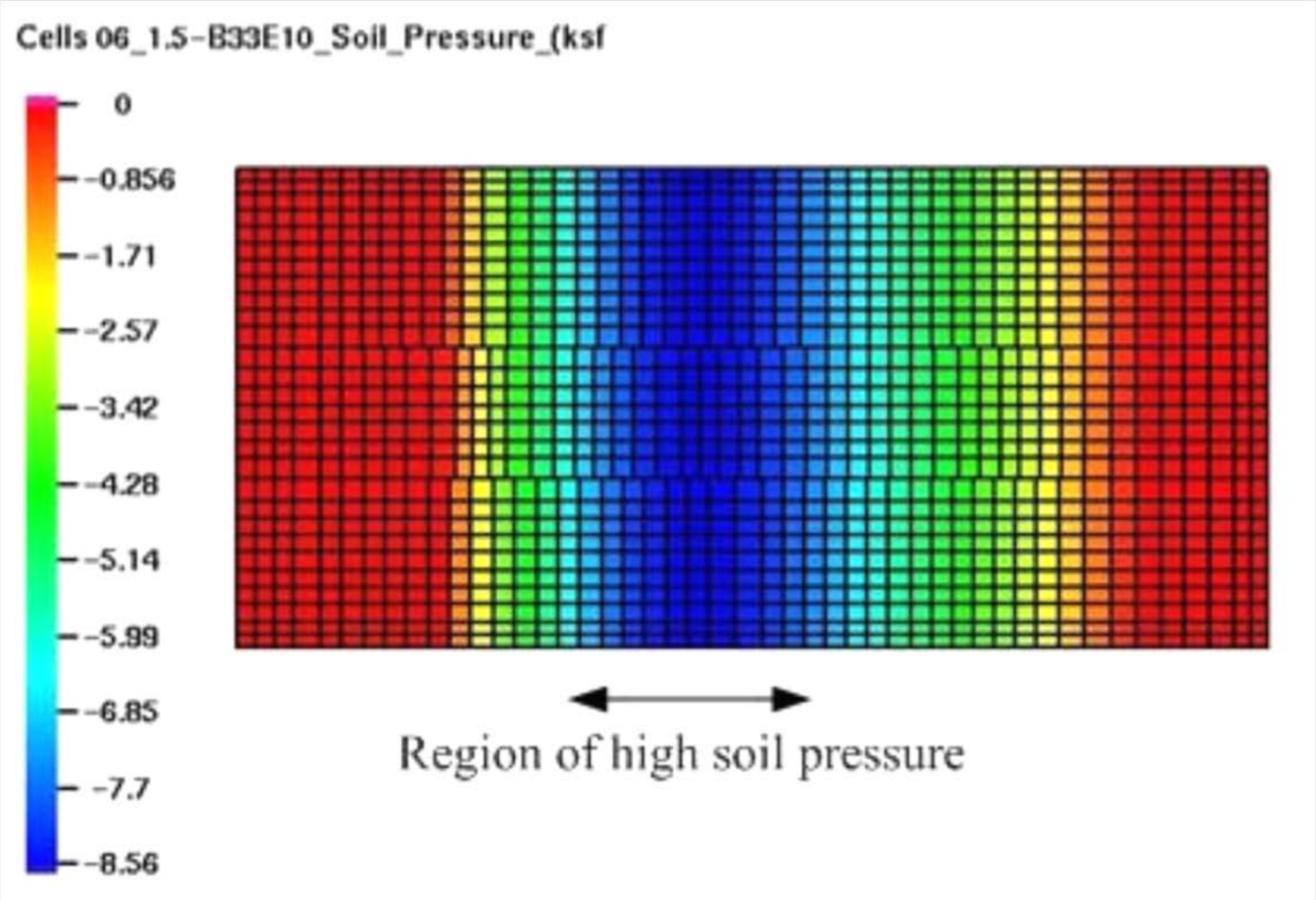


Simplified Slab Shear (klf)

Settlement Profile



Soil Bearing Pressure

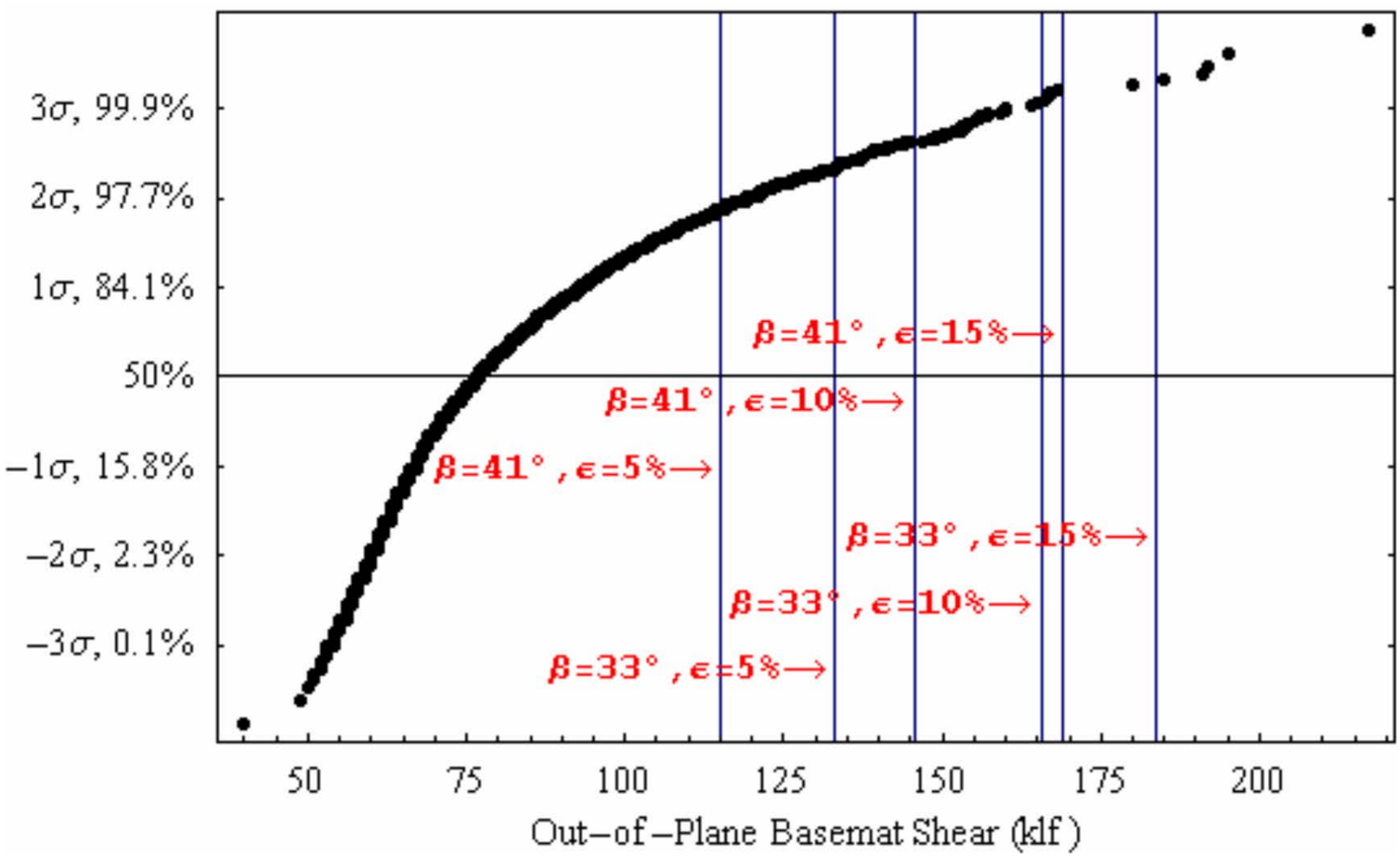


Soil Bearing Pressure (ksf)

Results Synthesis

- Building response values are developed for 10,000 simulations
- Observations are made regarding:
  – Fully probabilistic results to deterministic results
  – Single vs. Multiple Occurrences and Location of Soft Zone Region
  – Dependency of results on geotechnical parameters

Fully Probabilistic to Deterministic Results



Fully Probabilistic to Deterministic Results

- Previous figure shows that deterministic cases provide adequate conservatism and are consistent with ASCE-4
- These results are not unexpected when considering that the deterministic analyses intentionally combined conservative estimates of geotechnical parameters to maximize building response
- Conclusion:

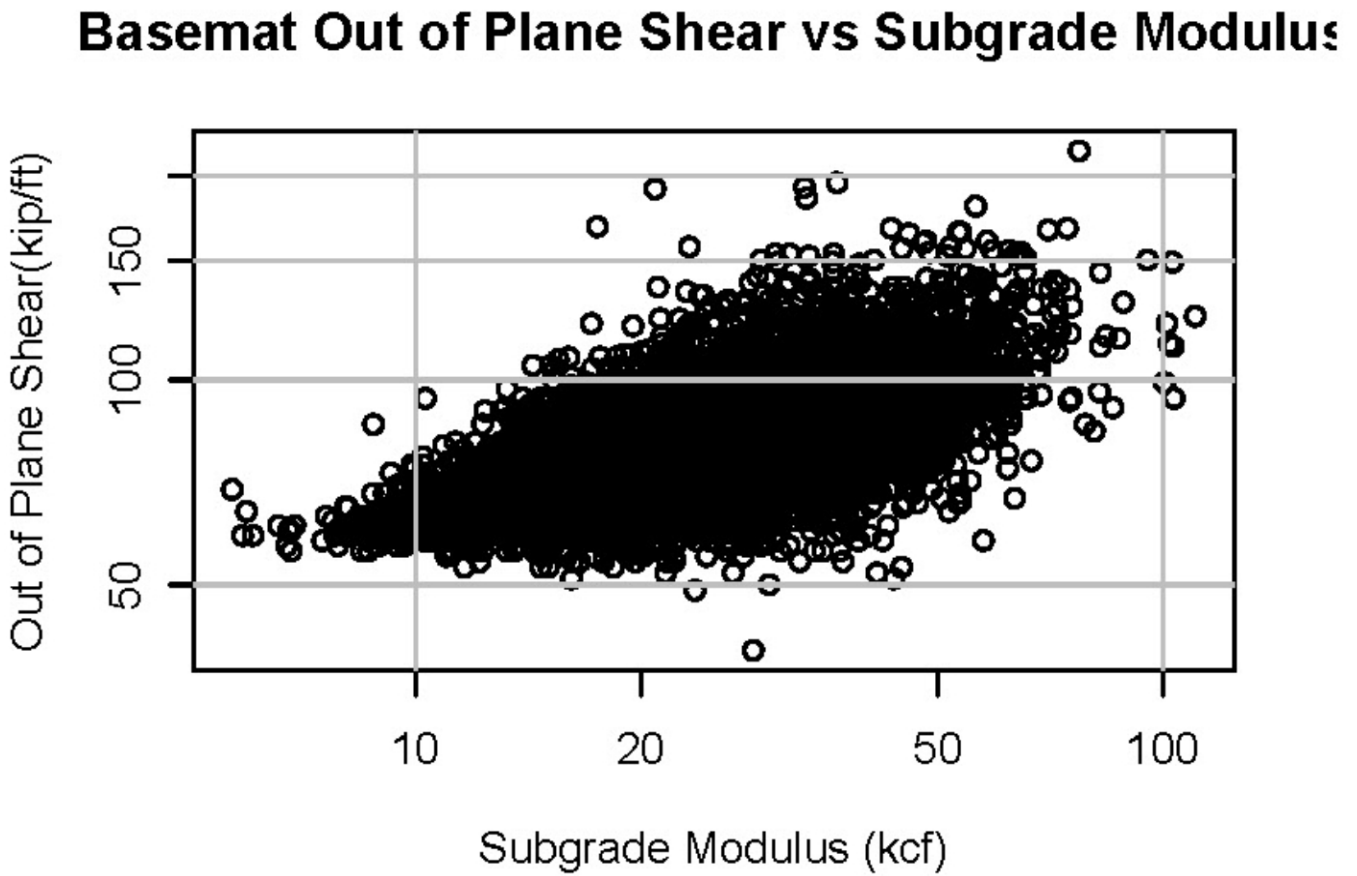
  Conservative selection of settlement parameters, settlement profile, and subgrade moduli result in very conservative building design loads

Single vs. Multiple Occurrences of Collapse and Location of Soft Zone Region

- Event trees for the maximum building demands indicate:
  - Mean demand computed from the 2-D and 3-D branches of the event trees are similar
  - Even large changes in the weighting between these two conditions will not significantly change the expected structural demands
- Conclusions:

  Structural demands are not overly sensitive to the weights assigned to these branches

Dependency of Results on Geotechnical Parameters



Dependency of Results on Geotechnical Parameters (2)

- Previous figure shows strong relationship of structural demands to subgrade modulus
- When combined with the variation of demands associated with the subgrade modulus, the remaining parameters showed moderate to small relationship with the resulting structural demands
- Trends from the remaining parameters
  - Narrower beta tends to lead to higher demands
  - Depth to top of soft zone has little effect
  - Moderate dependence on soft zone width
  - Moderate dependence on soft zone thickness

Why the Probabilistic Approach?

- Probabilistic approach has several useful advantages:
  - Identify the parameters that significantly affect structural demand
  - Assess margins that exist in a design
  - Identify sensitivities of the building demands to each parameter to determine which uncertain parameters should receive more scrutiny (i.e. subgrade modulus)
  - Permits development of estimates of margin against a facility not performing its required function, thus providing a more reasoned approach to selecting a design that meets DOE-STD-1020 requirements