

FGI Webinar: Reliability Analysis Of Landfill Slopes and Embankments



Presented by:

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Introduction & Background

This webinar introduced a paradigm shift in slope stability analysis, moving from traditional deterministic factor of safety (FOS) approaches toward a probabilistic reliability framework. The presentation demonstrated that a high FOS does not necessarily equate to a low probability of failure if significant uncertainty exists in the input parameters. This is particularly critical for landfill slopes and embankments, where consequences of failure can include significant environmental damage and potential loss of life. The methodology, based on Duncan's 2000 work, quantifies the uncertainty in key geotechnical parameters to calculate a probability of failure, providing a more rational and transparent basis for risk-informed design and communication with clients and regulators.

Limitations of Traditional Factor of Safety

- US EPA's 1993 technical manual provides recommended FOS values based on consequence of failure and uncertainty in strength measurements (1.25 for low-consequence/low-uncertainty to >2.0 for high-consequence/high-uncertainty scenarios).
- *Illustration:*
 - *Slope 1:* FOS = 1.5, high parameter uncertainty → higher probability of failure

- *Slope 2*: FOS = 1.35, low uncertainty → lower probability of failure
 - Demonstrates that FOS alone is insufficient to convey true stability risk.
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Probabilistic Methodology and Calculation

- Calculate Most Likely Value (MLV) of FOS using average/best-estimate parameters.
- Standard deviation of FOS (σ_{FOS}) calculated from ΔFOS when each parameter varies ± 1 standard deviation:

$$\sigma_{\text{FOS}} = \sqrt{\sum (\Delta\text{FOS}/2)^2} \text{ for all variables}$$

- Coefficient of Variation (COV) = $(\sigma_{\text{FOS}} / \text{FOS_MLV}) \times 100\%$
 - Probability of failure derived from standard statistical tables (normal/log-normal distributions).
 - Probability can be inverted to express stability as return period (e.g., 1% annual failure = 100-year return period).
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Practical Application Examples

- *Retaining wall*: interface friction angle & earth pressure coefficient dominate uncertainty; probability of failure = 0.7% (~1 failure per 143 years).
 - *Underwater slope, San Francisco Bay mud*: FOS_MLV = 1.17, high uncertainty → probability of failure = 20% (~1 failure per 5 years, matching actual failure).
 - Highlights method's ability to identify critical parameters and provide realistic risk assessment.
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Target Probability of Failure for Landfills

- Historical embankment dam data suggests acceptable annual probability of failure $\sim 1 \times 10^{-4}$ (1 in 10,000 years).
 - Can integrate with F-N curves (probability vs. consequences) used by US Bureau of Reclamation/Army Corps.
 - Designers can work backward from desired consequence/service life to determine required FOS_MLV and maximum allowable parameter uncertainty.
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Quantifying Uncertainty in Input Parameters

- *Challenge*: limited site investigation data.
 - *Three-Sigma Rule*: Standard Deviation $\approx$ (Highest Conceivable Value – Lowest Conceivable Value) / 6 (captures 99.7% of normal distribution).
 - Typical COV ranges for geotechnical parameters:
 - Unit weight: 3–7%
 - Effective friction angle: 2–13%
 - Undrained shear strength: 13–40%
 - Most influential uncertain parameters: geosynthetic interface and municipal solid waste (MSW) shear strength.
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Landfill-Specific Analysis and Critical Findings

- Appropriate selection of interface strengths (peak, large-displacement, residual) is crucial.
- Using peak strengths throughout yields high FOS (2.0) but is unconservative.

- Large-displacement/residual strength application: $FOS_{MLV} = 1.05$.
 - High interface strength uncertainty (COV ~9.5%) → probability of failure 31–32% (~1 failure every 3 years).
 - Underscores critical importance of characterizing and applying interface strengths correctly.
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The Importance of Shear Stress-Displacement Behavior

- Standard direct shear tests stop at 75 mm displacement; ring shear tests show continued softening to true residual strength.
 - Recommended: power function $\tau = \alpha * \delta^\beta$ to extrapolate residual strength for stress-deformation analyses.
 - Non-extrapolated data can overestimate FOS by >18%.
 - Modeling waste as more compressible (Modified Cam-Clay vs. Mohr-Coulomb) increases predicted displacement, reducing FOS further.
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Conclusions and Recommendations

The reliability approach is superior for evaluating slope stability.

Geosynthetic interface strength dominates probability of failure. Designers should:

- Increase interface strength (e.g., higher texturing/asperity height).
- Improve consistency (reduce variability) via QA/QC and manufacturing control.
- Use power function to extrapolate direct shear test data to true residual strength.
- Select strength parameters based on anticipated shear displacement (function of slope geometry and waste compressibility).

- Focus site investigation on most influential parameters; minor parameters (e.g., waste unit weight) have minimal impact.

Additional Information

A full recording of the webinar and presentation slides were made available on the Flexible Geomembrane Institute website.

Next webinar: *Migrating from the Simplified Method to the AASHTO Stiffness Method for MSE Walls* (Professor Richard Bathurst, July 18, 2024).

Dr. Lin addressed attendee questions; remaining questions will be answered in a follow-up podcast.

A spreadsheet for extrapolating direct shear data using the power function may be provided by the presenters.