



Slope Stability

Course Number: GE-02-405

PDH: 3

Approved for: AK, AL, AR, DE, FL, GA, IA, ID, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, NJ, NM, NV, NY, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, VT, WI, WV, and WY

State Board Approvals

Florida Provider # 0009553 License #868

Indiana Continuing Education Provider #CE21800088

Maryland Approved Provider of Continuing Professional Competency

New Jersey Professional Competency Approval #24GP00025600

North Carolina Approved Sponsor #S-0695

NYSED Sponsor #274

How Our Written Courses Work

This document is the course text. You may review this material at your leisure before or after you purchase the course.

After the course has been purchased, review the technical material and then complete the quiz at your convenience.

A Certificate of Completion is available once you pass the exam (70% or greater).

If a passing grade is not obtained, you may take the quiz as many times as necessary until a passing grade is obtained).

If you have any questions or technical difficulties, please call (508) 298-4787 or email us at admin@PDH Pro.com.



Module 1: Design Fundamentals and Site Characterization

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the essential geological and material characteristics required for a comprehensive site characterization in slope stability analysis.
- **Evaluate** the limitations of various limit equilibrium methods and the specific risks associated with strain softening and progressive failure.
- **Select** appropriate 2-D analysis procedures and loading conditions to ensure the structural integrity of embankments, dams, and natural slopes.

Executive Summary: Successful slope stability design is a holistic process where the factor of safety is inseparable from the specific procedures used to measure shear strength and analyze stability. Engineers must prioritize methods that satisfy all conditions of static equilibrium to avoid significant inaccuracies.

Purpose and Scope

This module provides guidance for analyzing the **static stability** of slopes for earth and rock-fill dams, embankments, excavations, and natural slopes in soil or soft rock.

⚠ Safety Constraint: The criteria presented must be used with stability analysis methods that satisfy **all conditions of equilibrium**. Methods that do not satisfy all conditions may involve significant inaccuracies and are only permitted under specific, restricted conditions.

Applicability

These guidelines apply to all design elements and field operations responsible for slope stability analysis.

Notation and Glossary

Symbols are defined in Appendix B and generally follow **American Society of Civil Engineers (ASCE)** standards.

Basic Design Considerations

Site Characterization

Stability evaluations must utilize pertinent geologic information and in situ engineering properties. Key factors include:

- **Hydrogeology:** Groundwater and seepage conditions.
- **Lithology and Stratigraphy:** Details disclosed by borings and geologic interpretations.
- **Geological History:** Maximum past overburden.
- **Structural Geology:** Bedding, folding, faulting, and joint systems.
- **Material Alteration:** Weathering, cementation, slickensides, and fault-induced changes.
- **Field Evidence:** Historical slides, earthquake activity, or tension jointing.

Material Characterization

When selecting design parameters, engineers must account for:

1. Variations in natural deposits or borrow materials.
2. Natural water contents and climatic conditions.
3. Construction variables (fill placement rates, compacted densities, and water content).
4. **Engineering Judgment:** Effects of differential settlements and stress-strain compatibility between different material zones.

Conventional Analysis (Limit Equilibrium)

Limit equilibrium methods investigate the equilibrium of a soil mass tending to move downslope.

- **2-D Analysis:** Standard practice assumes plane strain conditions.
- **Factor of Safety (FS):** Defined as the ratio of available shear resistance (**capacity**) to the shear resistance required for equilibrium (**demand**).
- **Methods of Slices:** The soil mass is divided into vertical slices. Different methods (e.g., Spencer, Simplified Bishop) may yield different FS values based on their underlying assumptions regarding static determinacy.

Special Analysis Procedures

- **Finite Element Method (FEM):** Useful for soil-structure interaction and computing displacements, but stability cannot be determined directly without complex processing.
- **3-D Analysis:** Not recommended for general design due to limitations in locating the most critical 3-D slip surface and lack of equilibrium satisfaction in most current methods.
- **Probabilistic Methods:** Encouraged as a supplement to deterministic methods to evaluate the degree of **uncertainty** in shear strengths and other parameters.

Strain Softening and Progressive Failure

💡 **Design Tip:** If peak strength is mobilized anywhere along a failure surface in strain-softening materials, the slope is at risk of **progressive failure**.

Consider these factors:

- **Undrained Strength Loss:** Often caused by contraction-induced pore water pressure (extreme case: liquefaction).
- **Drained Strength Loss:** Resulting from dilatancy in dense soils.
- **Slickensides:** Reorientation of clay particles into parallel arrangements with low resistance.
- **Remedy:** In such cases, use shear strengths lower than peak values, or even **residual strengths**.

Strain Incompatibility and Tension Cracks

- Dissimilar materials (e.g., stiff embankments over soft clay) may not mobilize peak strength simultaneously.
- **Tension Cracks:** Ignore shear resistance along cracks. Assume cracks fill with water during rainfall, increasing driving forces.

Problem Shales

- **Clay Shales:** Lack cementation and slake rapidly.
- **Cemented Shales:** Held by chemical bonds; more resistant to wetting/drying.
- **Warning:** Field behavior of clay shales should be based on detailed geologic investigations rather than laboratory tests alone.


Stability Analysis and Design Procedure

The evaluation process follows this sequence:

1. **Explore/Sample:** Foundation and borrow sources.
2. **Characterize Strength:** Test representative samples (Appendix D).
3. **2-D Idealization:** Establish cross-section geometry and material boundaries.
4. **Pore Pressure:** Predict seepage and groundwater conditions.
5. **Select Loading:** Define analysis conditions (Chapter 2).
6. **Analyze:** Compute FS using **Spencer's Method** (preferred) or Simplified Bishop/Modified Swedish.
7. **Locate Critical Surface:** Iteratively find the surface with the lowest FS.
8. **Compare:** Verify against experienced-based criteria (Chapter 3).
9. **Verify:** Confirm assumptions during construction and monitor performance via piezometers and movement points.

Unsatisfactory Slope Performance

- **Shear Failure:** Sliding along a discrete surface (often circular).
- **Surface Sloughing:** Surficial movement; primarily a maintenance issue but can escalate if ignored.
- **Excessive Deformation:** High-strain cohesive soils may require using strengths at 10-15% strain rather than peak.
- **Liquefaction:** Significant strength loss in saturated loose sands/silts during earthquakes.
 - *Note: Soils with $PI \geq 14$ or $LL \geq 34$ are generally not susceptible.*
- **Piping:** Internal erosion caused by high hydraulic gradients.

 **Calculation Note:** When strains greater than 15% are required to mobilize peak strength, deformations may be excessive for the structure's intent.

Checkpoint Quiz

1. Which of the following describes the Factor of Safety (FS) in limit equilibrium analysis?

- a) The ratio of total stress to effective stress.
- b) The ratio of available shear resistance to the shear resistance required for equilibrium.
- c) The ratio of driving moments to resisting moments only.
- d) The probability that the slope will not fail.

Answer: (b). In geotechnical slope stability, the Factor of Safety is fundamentally a "strength reduction factor." It represents the factor by which the available shear strength (capacity) must be divided to bring the slope into a state of bare equilibrium (demand). While option (c) describes FS for simple moment-based methods, the general definition for all limit equilibrium methods is the ratio of capacity to demand.

2. Why is Spencer's Method generally preferred over the Simplified Bishop Method?

- a) It is easier to calculate by hand.
- b) It ignores inter-slice forces.
- c) It satisfies all conditions of static equilibrium (both force and moment).
- d) It is only applicable to circular slip surfaces.

Answer: (c). The Simplified Bishop Method only satisfies vertical force equilibrium and overall moment equilibrium; it neglects inter-slice horizontal forces. Spencer's Method is a "complete" equilibrium method because it accounts for both inter-slice forces (resultant force inclination) and moments for every slice. This makes it more rigorous and applicable to a wider variety of slip surface shapes (both circular and non-circular).

3. In materials prone to "strain softening," what is the primary risk of relying on peak shear strength for design?

- a) Overestimation of pore water pressure.
- b) Progressive failure, where local strength loss leads to a chain reaction of instability.
- c) The soil becoming too dense during shearing.
- d) Sudden increase in cementation.

Answer: (b). Strain softening materials (like stiff-fissured clays) lose strength after reaching a peak. If the peak strength is reached at any single point along a potential failure surface, that point "softens" and sheds its load to adjacent areas. This can trigger a "domino effect" or progressive failure where the entire slope fails even if the average FS based on peak strength was calculated to be greater than 1.0.



Purchase this course to
see the remainder of
the technical materials.