Schnabel ENGINEERING

SLOPE STABILITY AND SYSTEM FORCES

Developed by:
Dr. Jesús Gómez, P.E., D.GE

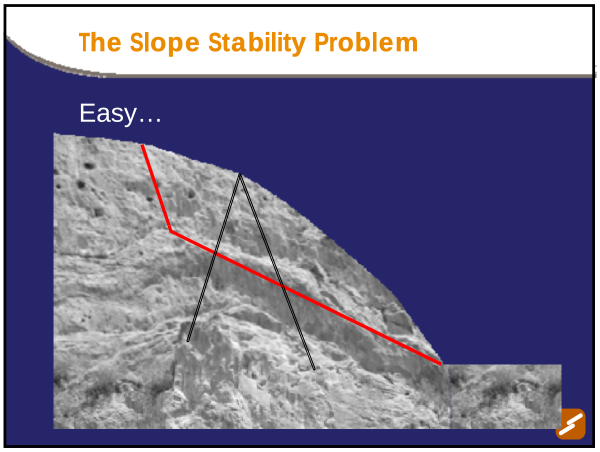
Outline

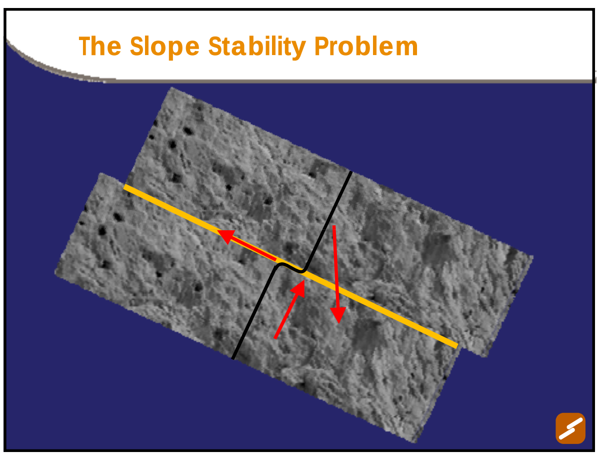
- Single micropiles stabilizing rock blocks
- Single micropiles stabilizing infinite soil layer on rock
- A-Wall cases
- General Slope Stabilization case
- Closure

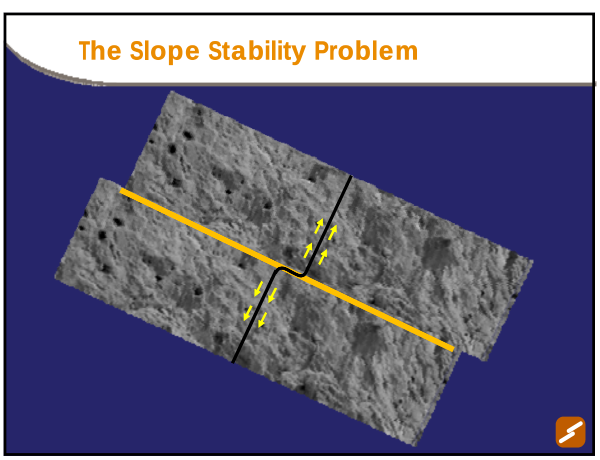
The Slope Stability Problem

Easy…

Very Hard Rock


The Slope Stability Problem
Easy…

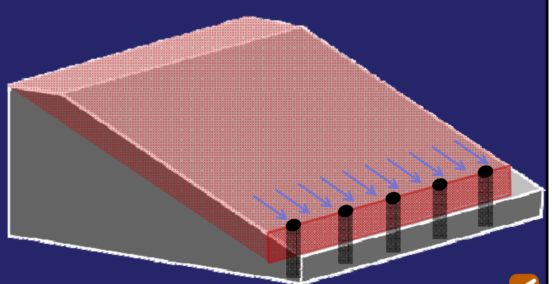

The Slope Stability Problem

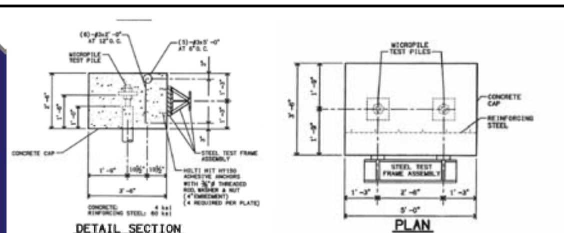

The Slope Stability Problem

Stabilization of Very Hard Rock Slopes

- If slip surface is planar and narrow
- If rock is very hard and stiff
- Displacement distribution is uniform above and below slip surface
- Rock arches between micropiles
- Significant shear strain and shear stress at slip surface
- Micropile acts as a shear dowel and should be designed as such
- Tension load develops in micropile that must be resisted by its embedded portions above and below slip surface
- Bending not a design criterion
- FS is ratio between resistance provided by micropiles (upon reaching limit shear or tension) and the sliding component
- Connection at top (tie beam) may not perform a practical function unless required for tensile capacity (anchorage function)

Stabilization of Very Hard Rock Slopes

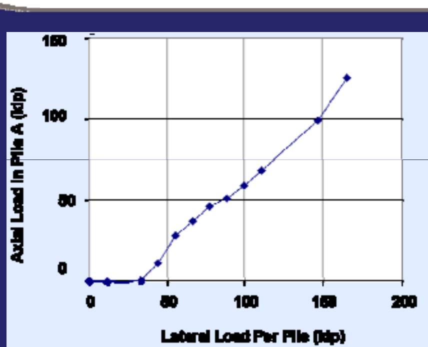




Lateral Load Test

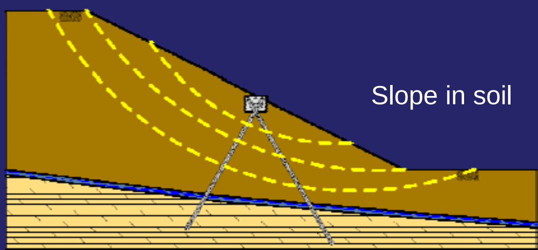
Lateral Load Test

Lateral Load Test



The Slope Stability Problem

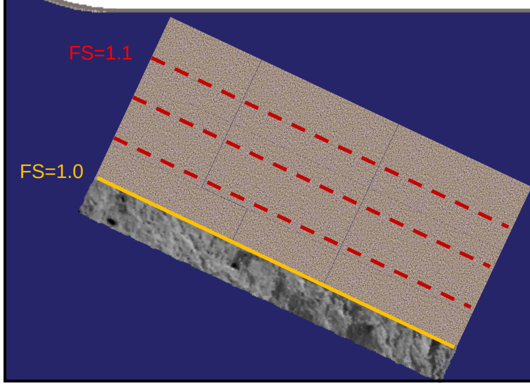
Not so Easy…



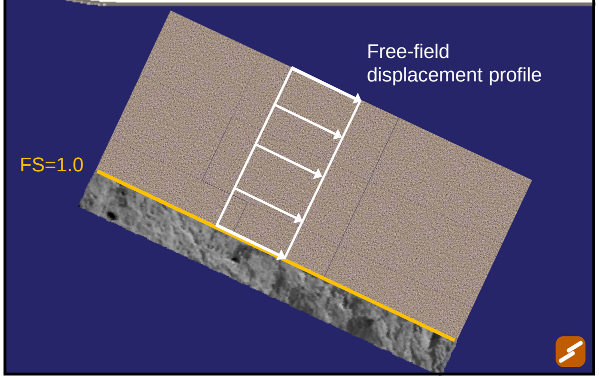
Stabilization of Soil Slopes

- Several critical slip surfaces need to be considered for design
- Position and shape of critical slip surfaces change with introduction of micropiles
- Displacement of soil is not uniform with depth
- Arching of soils between adjacent micropiles is more difficult to achieve. Design must carefully consider arching
- Micropile is not firmly constrained by soil
- Soil-Structure Interaction problem
- Finite Element or Finite Difference analyses may be suitable but difficult and do not model arching of soils (3-D problem) and require separate validation

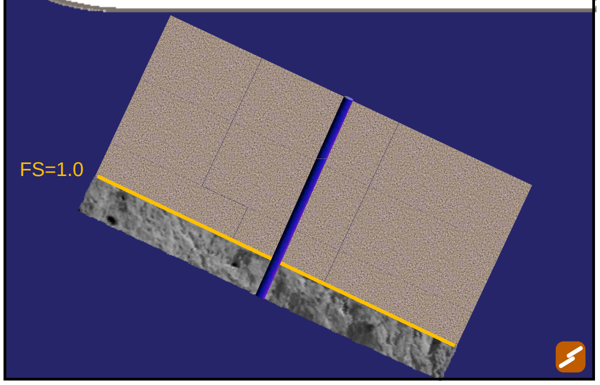
The Slope Stability Problem



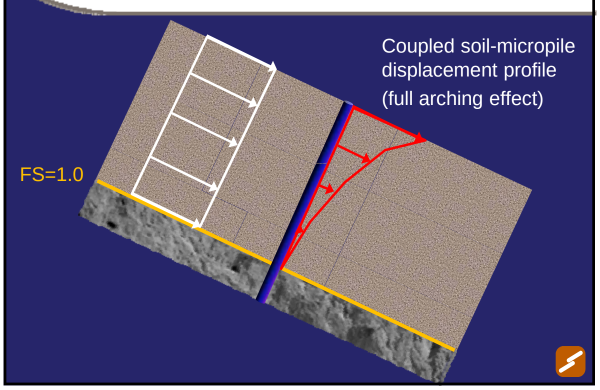
The Slope Stability Problem



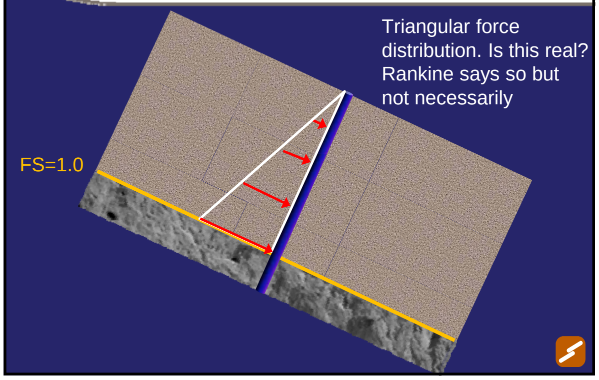
Let's introduce one micropile



Let's introduce one micropile



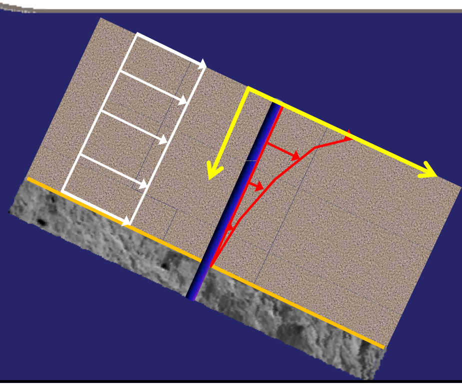
Forces on micropile



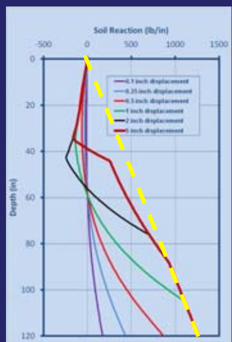
Lpile Analysis

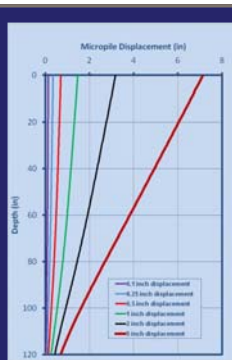
- Analyzed 7 inch micropile (t = 0.5 inch, Fy = 80 ksi)
- 10-foot thick soil layer with f = 28 degrees, k = 20 (low), g = 125 pcf
- Loose sand or silt (academic example)
- Micropile embedded in hard rock (3,000 psi limestone)
- Input several soil displacement levels from 0.1 to 5 inch in LPile

Rotated coordinate system

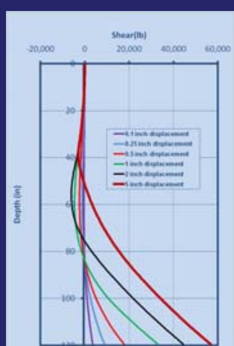


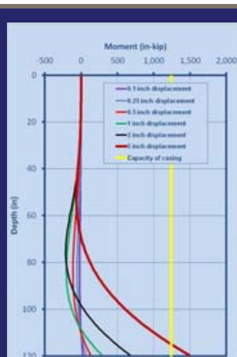
Lpile Analysis





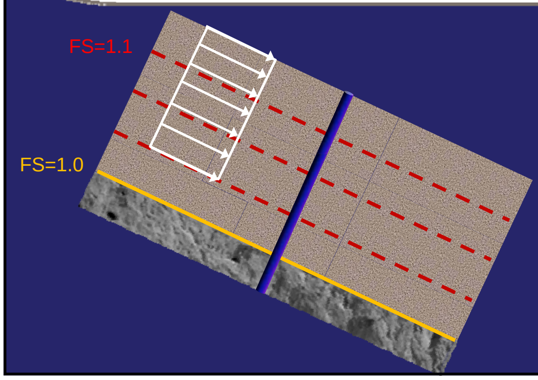
Lpile Analysis





Lpile Analysis

The Slope Stability Problem



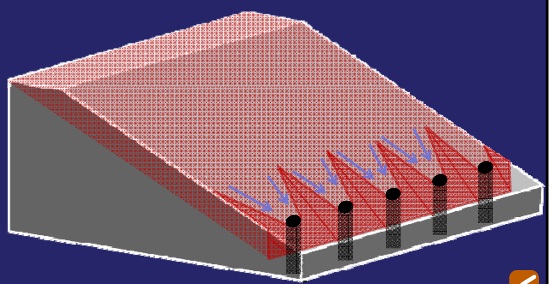
Lpile Analysis

- Based on this analysis, each micropile can contribute with about 50 kip to the shear capacity at the rock interface
- However, also need to analyze the slip surfaces within the soil layer
- The higher the slip surface, the less shear capacity provided by micropile (embedment in soil)
- But also, in this particular case, the higher the slip surface the less the required support force
- Typically, single micropiles do not work well for thickness of sliding soil of more than 7 to 10 ft, unless special measures are incorporated

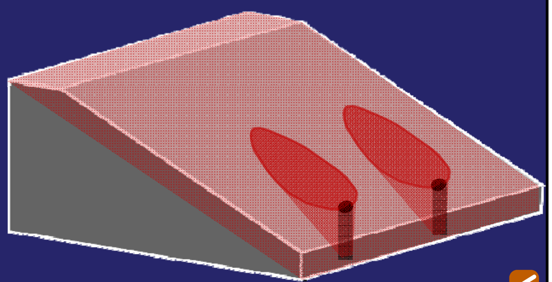
Lessons from Lpile Analysis

- This is the easiest case of micropile stabilization of soil slopes for analysis
- Not extremely common
- Useful in currently stable, relatively thin soil masses underlain by stiff soils or rock where an increase in the factor of safety is required
- Triangular distribution may be sufficiently close under the specific circumstances shown (infinite slope instability, purely frictional material, micropile embedded in rock)
- Can do simple analysis by hand but better use some form of Soil Structure Interaction analysis tool such as LPile

Arching



Micropiles too Spread Apart



Summary - Design of Simple One Micropile Case

- Run slope stability analyses and calculate required support force for given FS
- For the simple infinite slope case, hand calculation is sufficient but better use slope stability software
- Use Lpile or similar software that allows input of soil displacements instead of loads
- Calculate soil reaction, deflection, bending moment, shear along the micropile for various levels of soil displacement
- Find the level of soil displacement under which the micropile fails either geotechnically or structurally

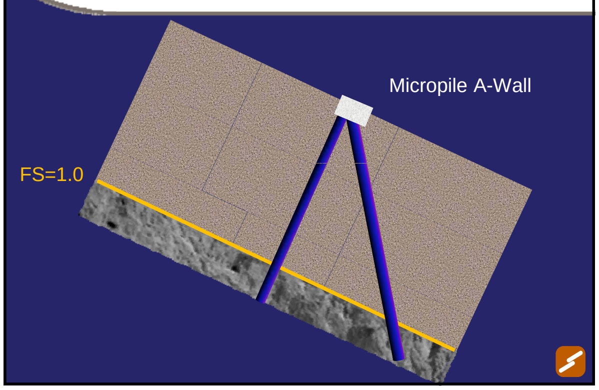
Summary - Design of Simple One Micropile Case

- In Lpile (finite difference analysis) the numerical solution may become unstable near failure.
  - Plot shear force in micropile at slip surface vs soil displacement and find point where the shear force is near a maximum
- If designing by hand, use progressively larger triangular distribution of force on the micropile (only in this case), and calculate deflection, bending moment, and shear along the micropile for each distribution. Same subsequent steps
- For pinned micropiles and for any other slope and soil configuration, do not assume the soil distribution unless there is previous confirmed experience at the particular site

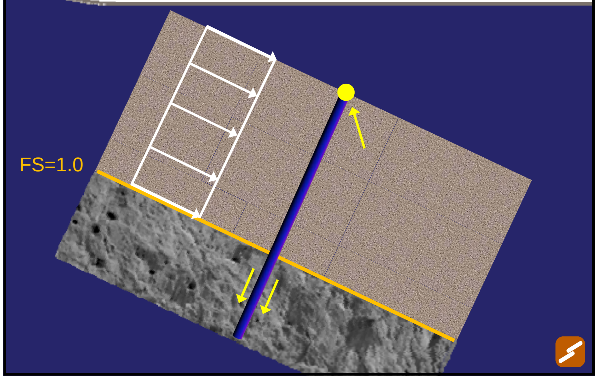
Summary - Design of Simple One Micropile Case

- The soil reaction is the resistance the micropile opposes to movement
- The maximum shear in the micropile at the slip surface under analysis is the maximum stabilizing force and must be equal or greater than the required force
- Make sure the software considers yielding of the micropile itself under bending. If not, separately check the maximum bending moment in the pile
- If short micropile embedded in very hard rock, check shear capacity as well
- Check soil arches between adjacent micropiles so there is no “flow” in between

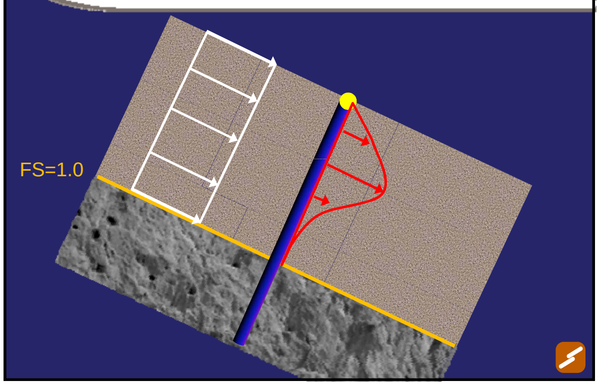
Let’s introduce a second micropile



Let's introduce a second micropile



Let's introduce a second micropile



Micropile A-Wall

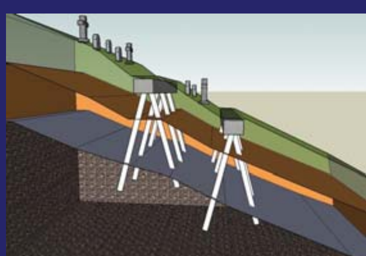
- Follow similar procedure as for single micropile case for EACH micropile
- Assume pinned condition at top
- Calculate maximum available resistance of each micropile
- Often, maximum resistance is given by soil reaction, not structural capacity of pile or soil resistance along embedment below slip surface
- Should consider axial forces, especially in compression pile. This requires one or more iterations of the LPile analysis
- Model shown is simplified
  - It assumes that the connection at the top is pinned
  - In reality, the cap rotates. If cap is properly designed, piles rotate together, which partially restrains top rotation
  - In reality, cap also translates as the micropiles compress or extend
  - Model suitable for short piles embedded in rock

Micropile A-Wall

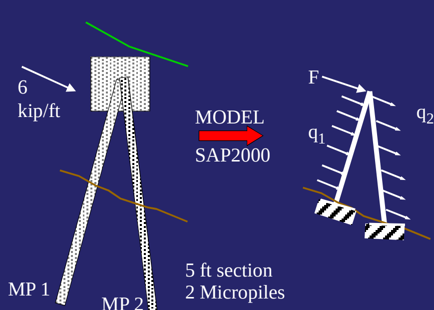
- Thorough modeling would require also analyzing the frame using a structural software and cross-feeding results iteratively with LPile
- Sounds worse than it really is
- The reason for considering the cap beam and adding structural frame software is to reduce construction costs. The presence of the cap beam generally decreases stresses in micropiles
- Erik Loehr has developed a design procedure that works as per experimental data

Oak Hill Cemetery, Washington, D.C.

TYPICAL A-WALL SECTION

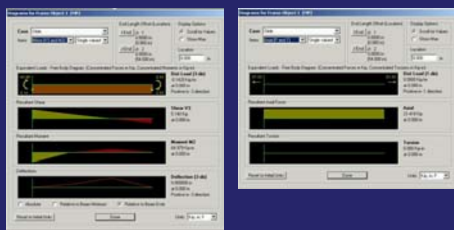


Structural Model

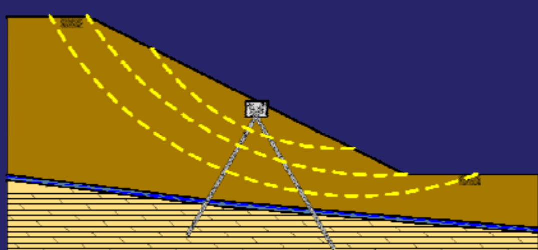


Frame Analysis

A-WALL SAP2000 OUTPUT



General Slope Stabilization Cases



General Soil Slope Stabilization

- Various critical slip surfaces with FS< required or <1
- Soil displacement pattern is not intuitive and cannot be guessed accurately
- Pick the most critical surface and calculate required force
- Run similar analyses as before but consider that the soil displacement is not orthogonal to all micropiles (axial component)
- Use a soil displacement profile that seems reasonable but conservative in all cases
- Run more analyses for various surfaces, including surfaces that encompass the micropiles altogether
- Run analyses downslope from micropile system
- Very cumbersome to run iterations on LPile and structural analysis. May ignore cap beam for analyses to make design process simpler and more conservative
- Consider cap beam in final solution only if necessary

Closure

- Slope Stabilization with Micropiles is simple to analyze under certain circumstances but most often it is not
- SSI problem
- First calculate required force for given FS from slope stability analyses
- Cannot distribute force arbitrarily on micropiles except in some simple cases
- Need to perform SSI analyses using LPile or similar
- May disregard cap beam if piles are sufficiently long into the sliding mass to develop the system axial forces. Still subject of discussion
- Disregarding cap beam is conservative
- To consider cap beam in analyses it is necessary to include structural frame analyses
- Spacing between micropiles must allow arching
- Always consider what happens downslope from micropiles