Design of Micropiles for Slope Stabilization

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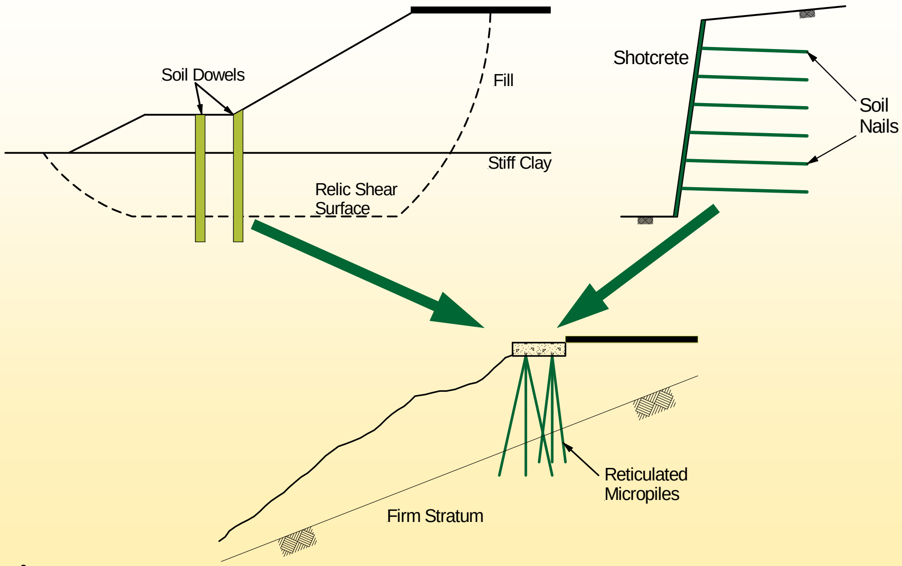
Outline

- Background
  - Typical implementation
  - Construction sequence
- Stability Analysis Issues
- Prediction of resistance for micropiles
- Comparison of predicted and measured resistance
- Summary and conclusions

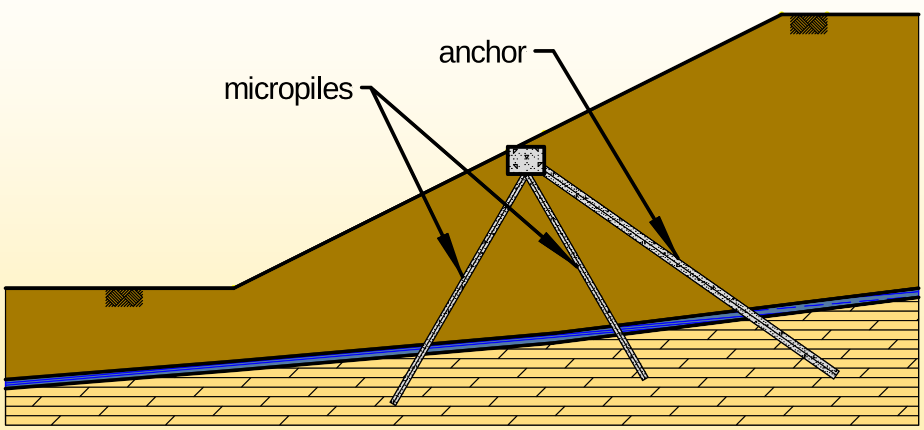
In-situ reinforcement schemes



3

after Bruce and Jewell, 1986

Common implementation



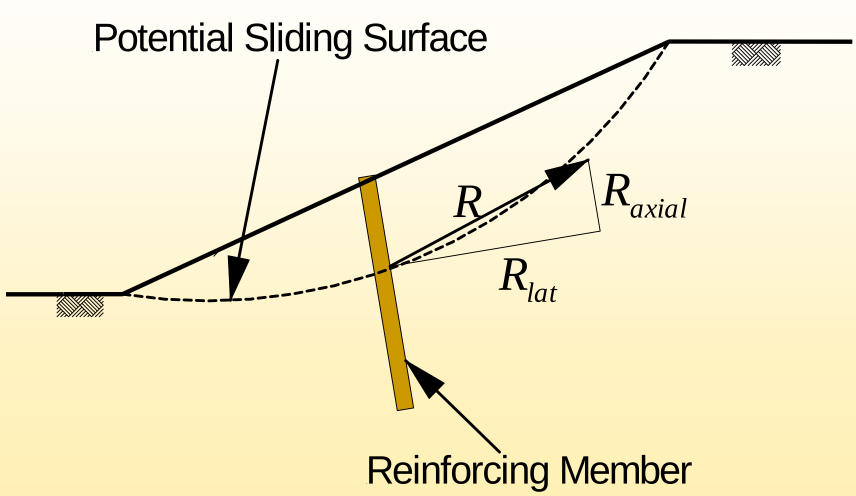
4

Oso Creek Landslide Stabilization

5

Photo courtesy of John Wolosick

Stability analysis for reinforced slopes



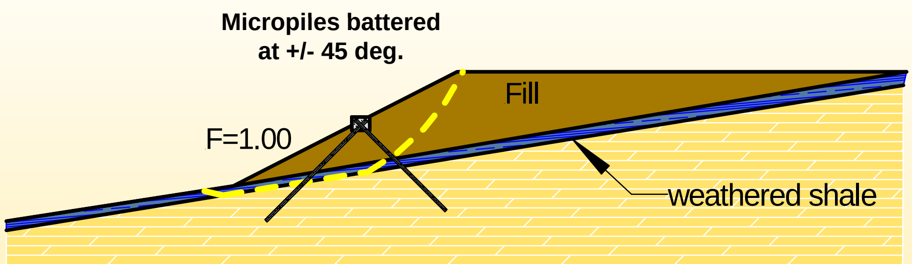
6

Stability analysis for reinforced slopes

- Same methods of analysis used for reinforced slopes
  - Same assumptions invoked
  - Same solution methods used
- Only change is to include magnitude of known force(s) into equilibrium calculations
  - Force must be consistent with “breadth” considered in stability analyses (i.e. force/unit width)
- Search for critical sliding surface can also become more challenging
  - Magnitude of resisting force changes with location
  - Numerous “local minima” frequently exist

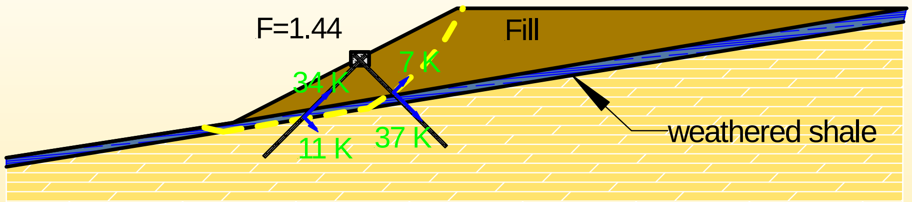
7

Example



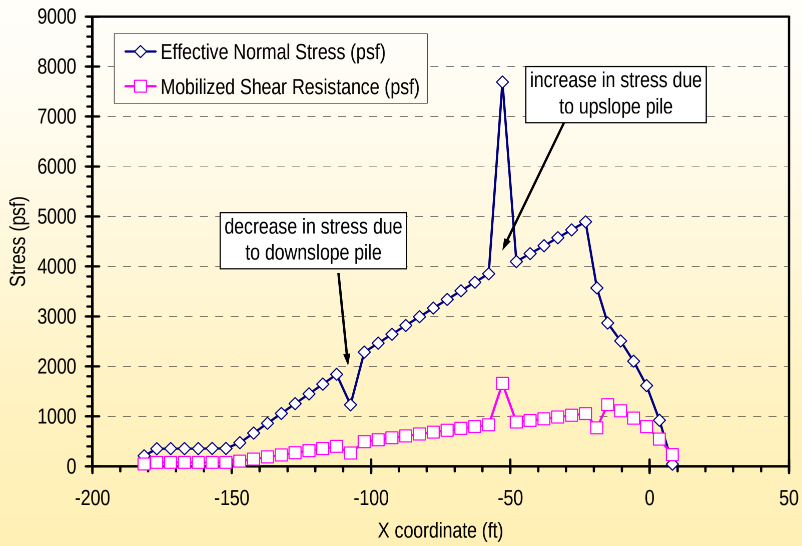
8

Result



9

Stresses on sliding surface



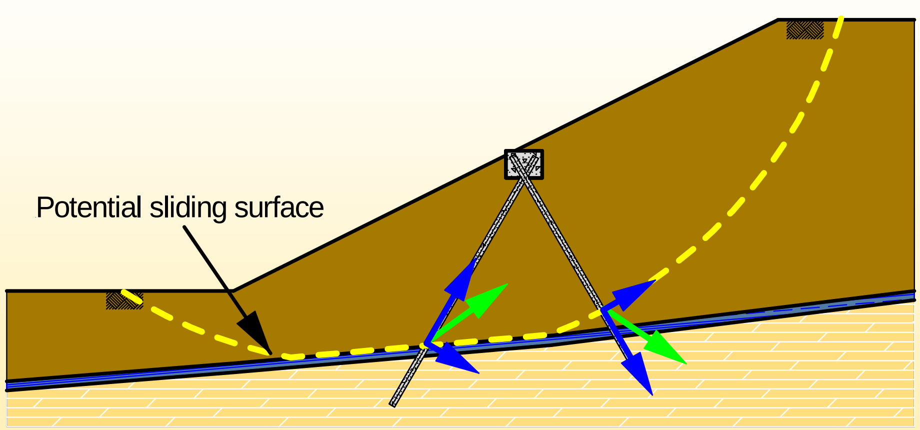
10

Impact of reinforcement on stability

- Reinforcement contributes to stability in two ways:
  - Direct resistance to sliding
  - Modifying normal stress on sliding surface
- Both of these can be significant
- Relative magnitude of contributions depends on:
  - Orientation of reinforcement w.r.t. soil movement
  - Type of reinforcement
  - Depth of sliding
  - Frictional resistance of soil

11

Prediction of micropile resistance



12

The challenge

- Micropiles are passive elements
- Soil provides both load and resistance…load transfer is complex
- Numerous limit states
- Must consider compatibility of axial and lateral resistance
- Must be able to mobilize resistance within tolerable deformations

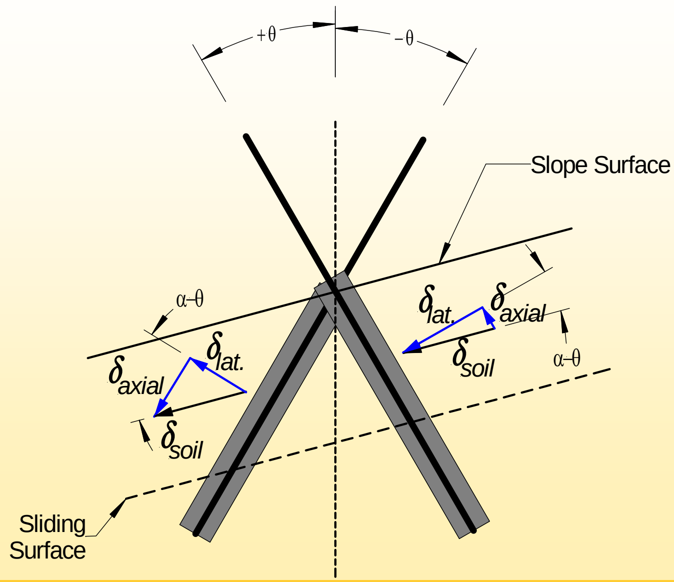
13

Prediction of micropile resistance

- Estimate profile of soil movement
- Resolve soil movement into axial and lateral components
- *Independently* predict mobilization of axial and lateral resistance
  - Using "p-y" analyses for lateral load transfer
  - Using "t-z" analyses for axial load transfer
- Select appropriate axial and lateral resistance with consideration given to compatibility and serviceability

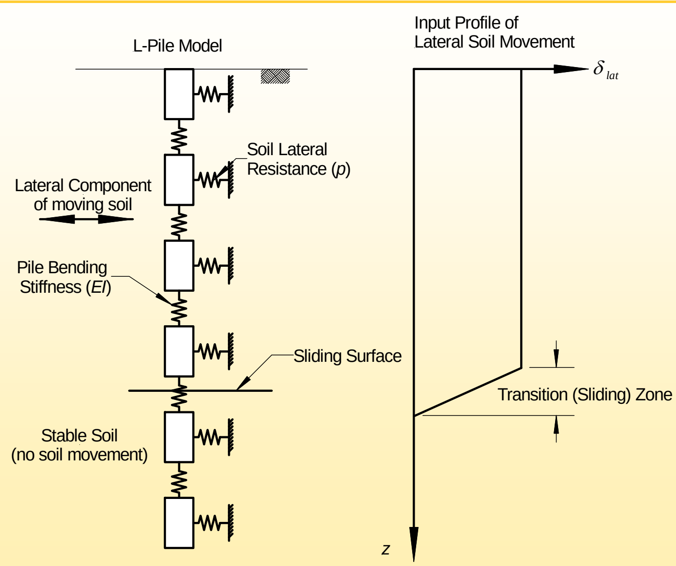
14

Soil movement components



15

p-y analyses for lateral resistance



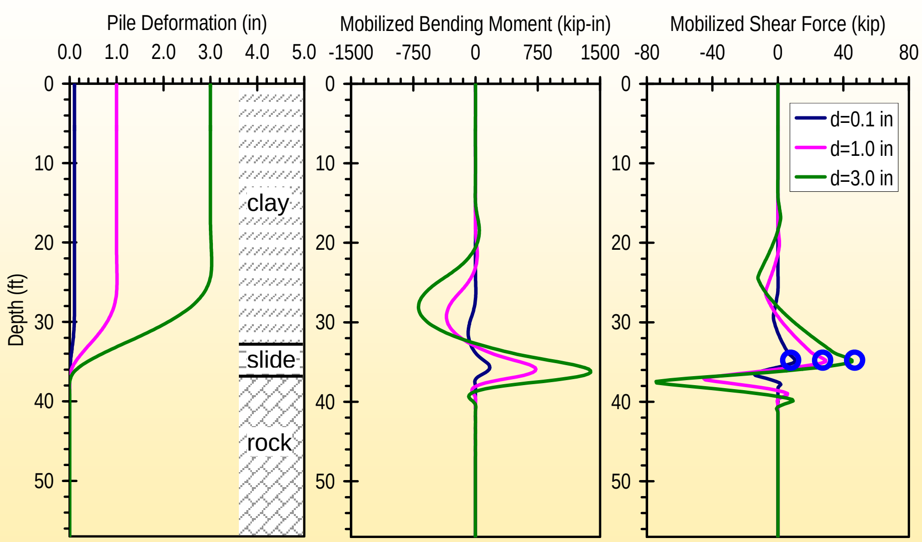
16

Lateral resistance from p-y analyses

- Use “soil movement” option (L-Pile v4.0M or v5)
- For an assumed depth of sliding:
  1. Apply displacements in soil above sliding surface
  2. Determine response from p-y analyses
  3. Mobilized resistance is shear force in micropile at depth of sliding
  4. Repeat steps 1 through 3 with incrementally increasing displacement until a limit state is reached
  - Shear force at sliding depth when first limit state is reached taken to be available resistance <u>for that sliding depth</u>
  - NOTE: MUST ALSO CONSIDER DEFORMATIONS REQUIRED TO MOBILIZE RESISTANCE

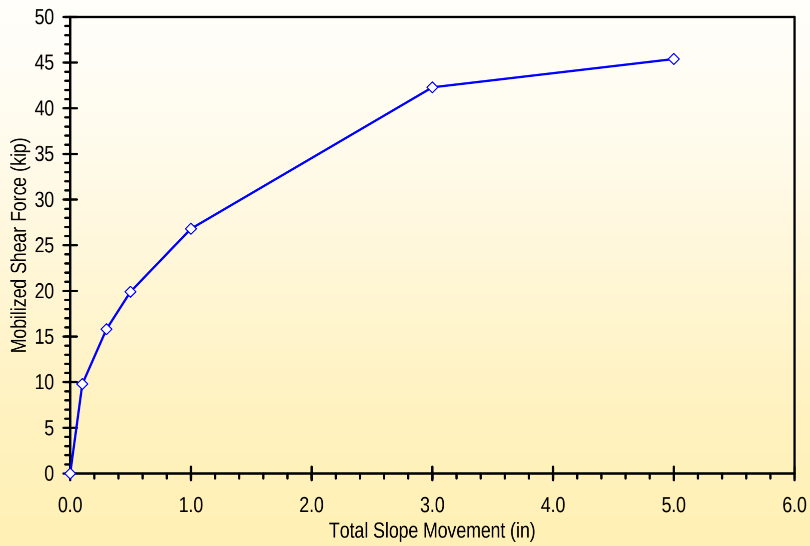
17

Mobilization of lateral resistance

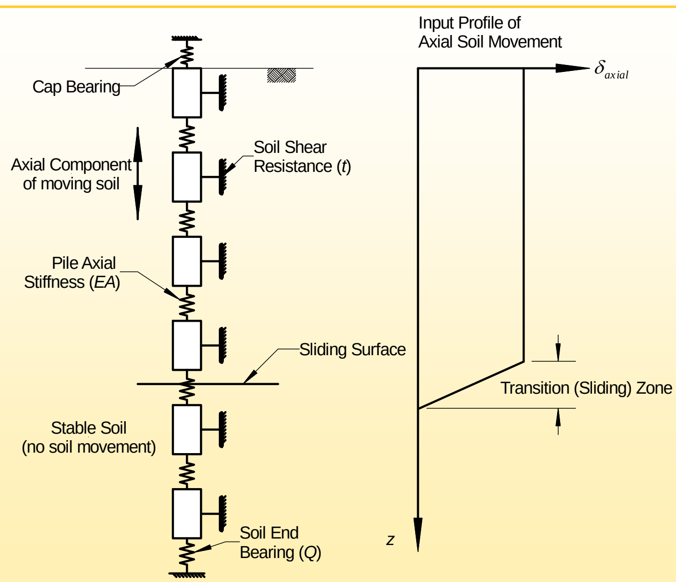


18

Mobilization of lateral resistance



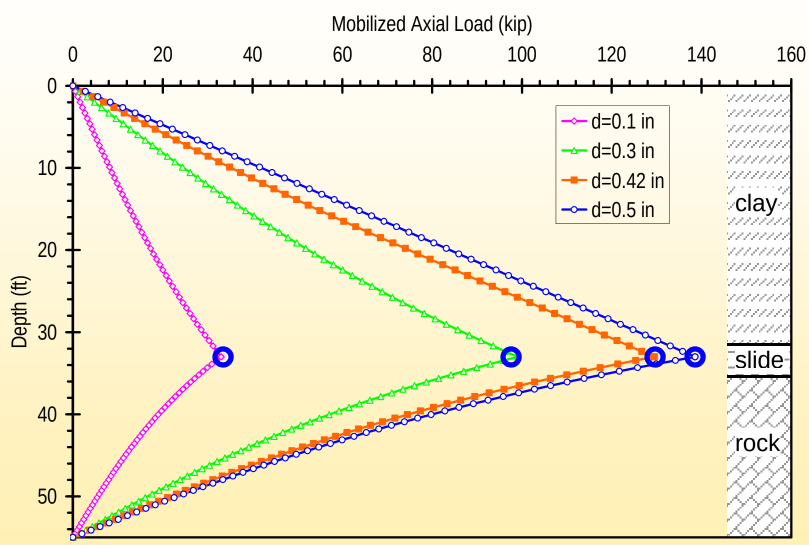
t-z analyses for axial resistance



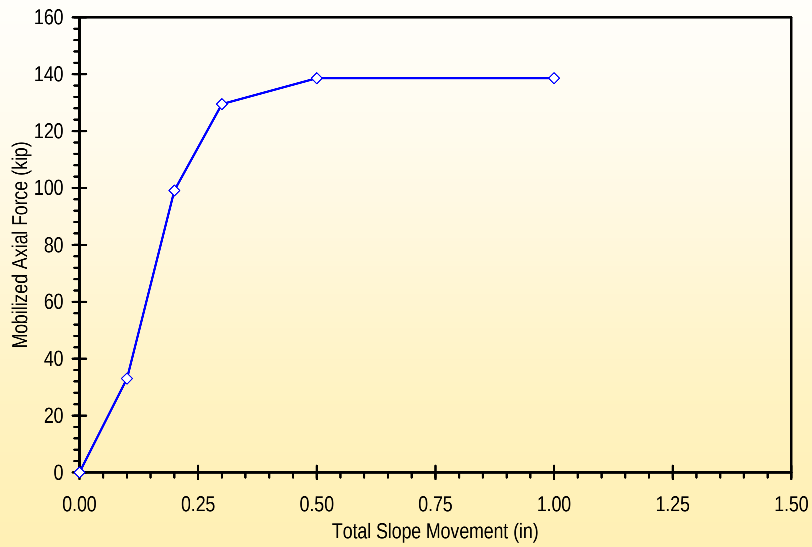
Axial resistance from t-z analyses

- For an assumed depth of sliding:
  1. Apply displacements in soil above sliding surface
  2. Determine response from t-z analyses
  3. Mobilized resistance is axial force in shaft at depth of sliding
  4. Repeat steps 1 through 3 with incrementally increasing displacement until a limit state is reached
  - Axial force at sliding depth when first limit state is reached taken to be available resistance for that sliding depth
  - NOTE: MUST ALSO CONSIDER DEFORMATIONS REQUIRED TO MOBILIZE RESISTANCE

Mobilization of axial resistance



Mobilization of axial resistance



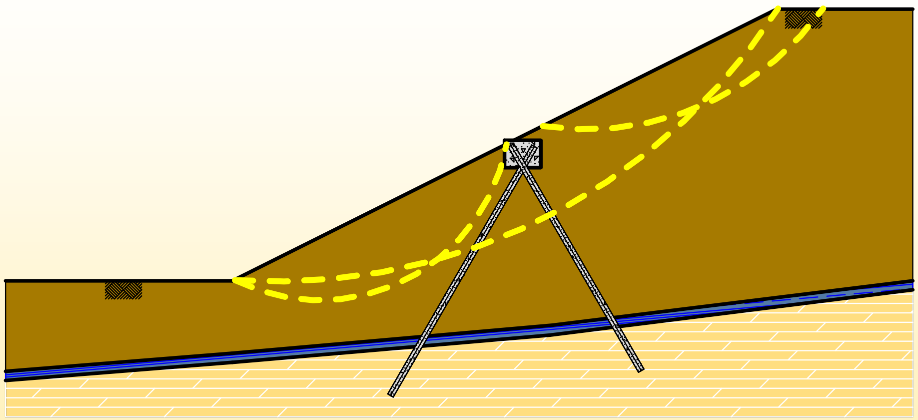
23

Limit states for soil reinforcement

- Soil failure
  - passive failure (lateral) above or below sliding surface
  - pullout failure (axial) above or below sliding surface
- Structural failure
  - flexural failure
  - shear failure
  - axial failure
    - compression
    - tension
- Serviceability limits

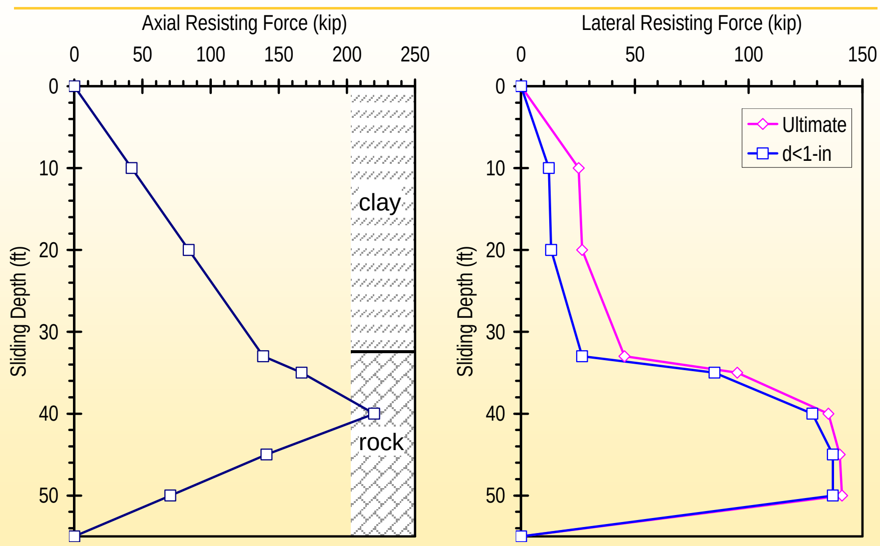
24

Repeat for other sliding depths…



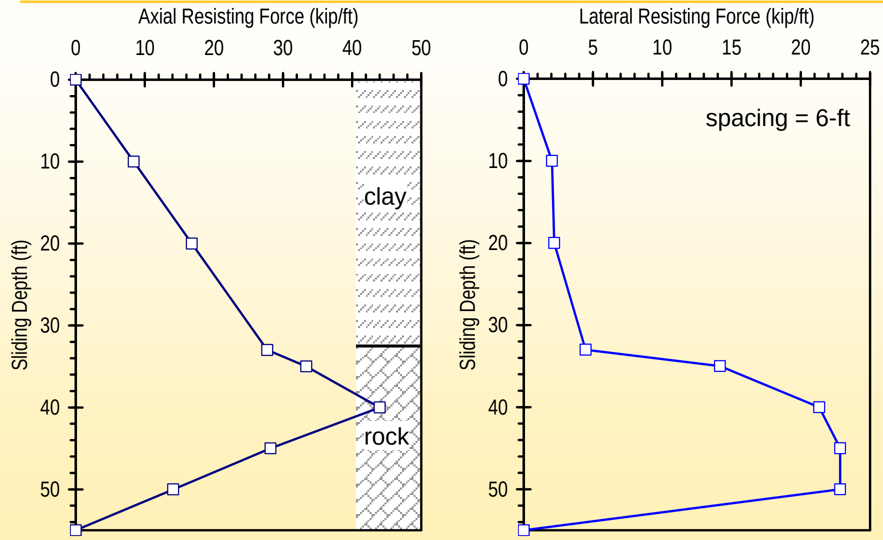
- Result is two resistance functions that describe resistance versus position along reinforcement

Resistance functions (per member)



Member resistance for individual member

Input for stability analyses (per lineal foot)



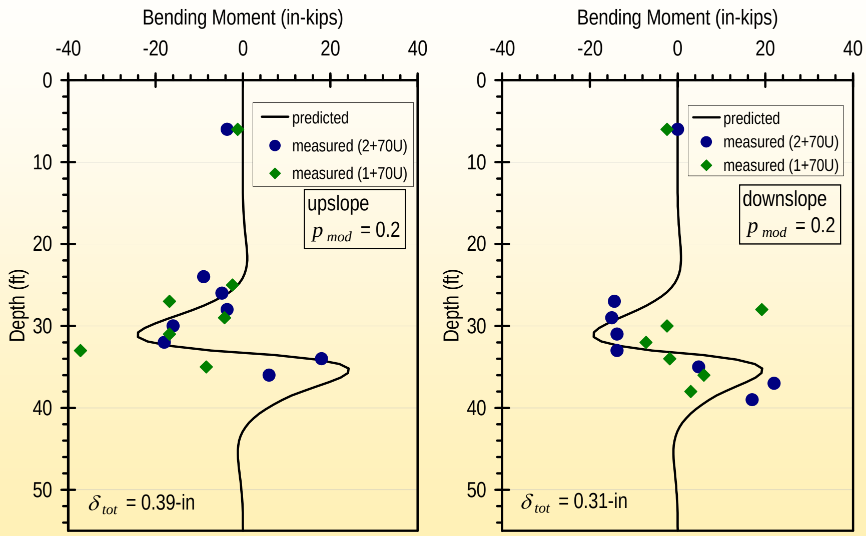
Member resistance divided by member spacing

27

Comparison w/ measured values

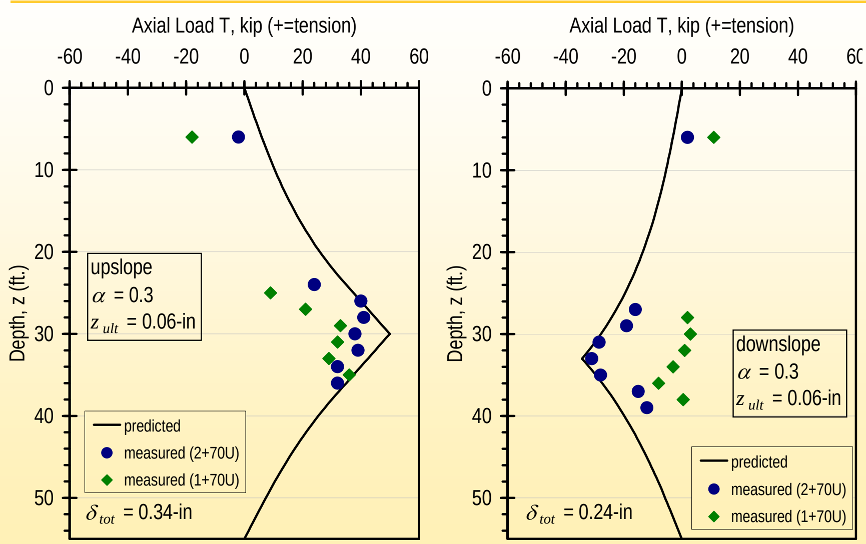
28

Mobilized bending moments – Littleville



29

Mobilized axial resistance – Littleville

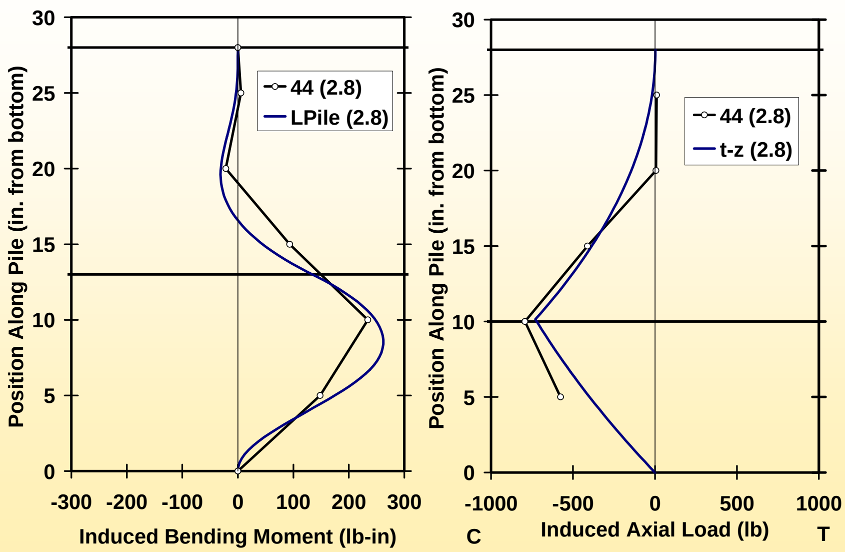


30

Large-scale model tests

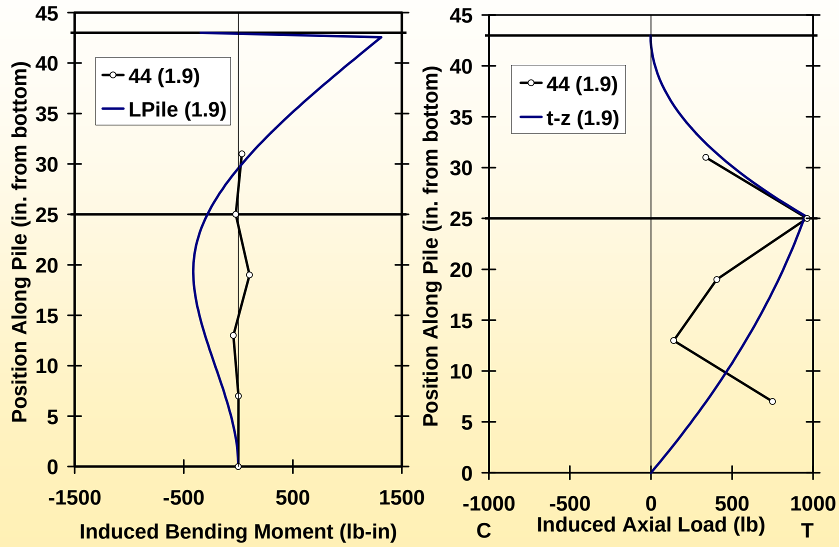
31

Model vs. measurement – no cap



32 Test 2-A, Member 3 (downslope), *S/D*=10

Model vs. measurement – with cap



33 Test 3-A, Member 2 (upslope), *S/D*=10

Summary and Conclusions

- Prediction of resistance for reinforcement requires consideration of soil-structure interaction
  - Cannot predict resistance based on structural capacity alone!!!
- Both axial and lateral components of resistance can substantially influence stability
  - Relative contribution depends on pile orientation and pile/soil characteristics
  - Axial resistance frequently mobilized at relatively small soil movements
  - Lateral resistance frequently requires greater soil movements
- *Uncoupled* method suitable for predicting resistance when no cap or when cap influence is limited
- Comparison of measured and predicted forces reasonable…BUT…may need to use *modified p-y and t-z models*
- Additional data needed!!!

34

Acknowledgements

- ADSC/DFI Micropile Committee
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- Many students…