LESSON 5

TOPIC 2

Solutions to Slope Instability

SOLUTIONS TO SLOPE INSTABILITY

Lesson 5 - Topic 2

Slide 5-2-1

SOLUTIONS TO SLOPE INSTABILITY

1. Discuss Solutions to Stability Problems

ACTIVITIES: Stability Problem Solving

Slide 5-2-2

Solutions to Slope Stability Problems

- ***Change Alignment***
- ***Lower Grade***
- ***Counterberm***
- ***Excavate & Replace Weak Soil***

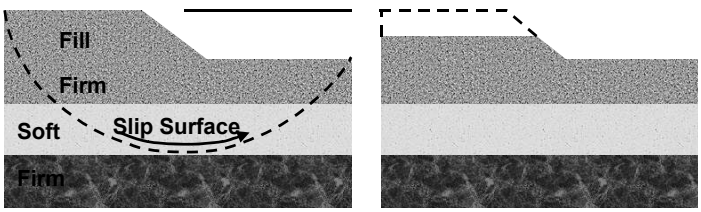
Slide 5-2-3

Solutions to Slope Stability Problems (Cont'd)

- ***Stage Construct Fill***
- ***Displace Weak Soil***
- ***Ground Improvement***
- ***Lightweight Fill***

Slide 5-2-4

Reduce Grade



Foundation Overstressed **Reduced Load**

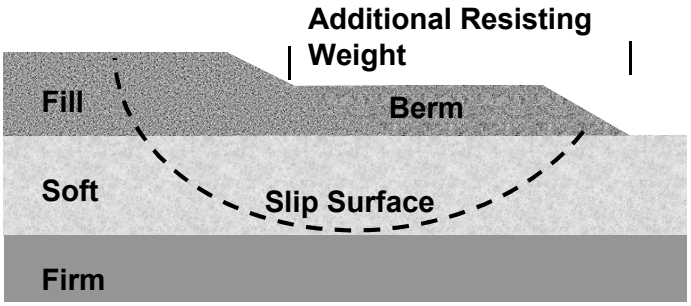
Effect: Reduces Driving Weight

Slide 5-2-5

Slide 5-2-6

Slide 5-2-7

Counter Berm

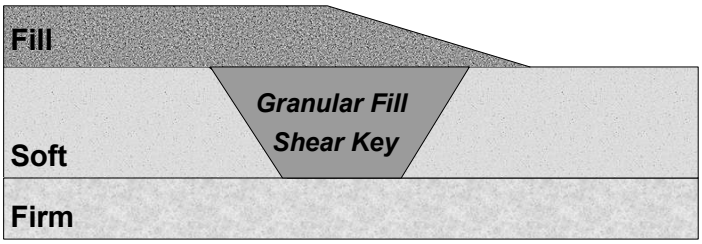


Effect: Provides Resisting Weight

Slide 5-2-8

Slide 5-2-9

Excavate and Replace Weak Soil

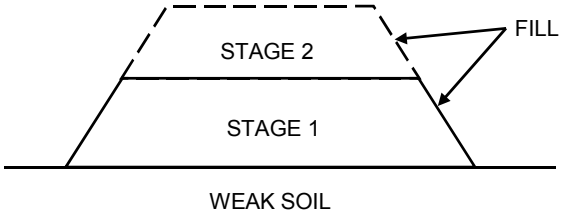


Effect: Stronger Soil Resists Sliding

Slide 5-2-10

Slide 5-2-11

Fill Stage Construction



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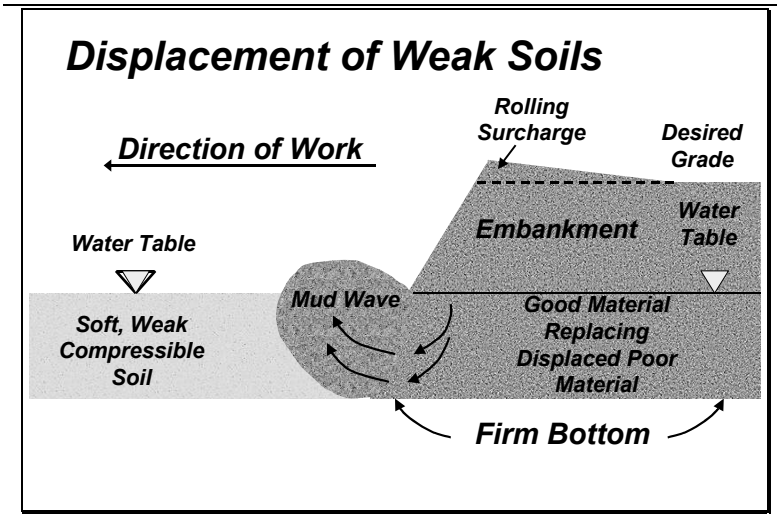
Slide 5-2-13



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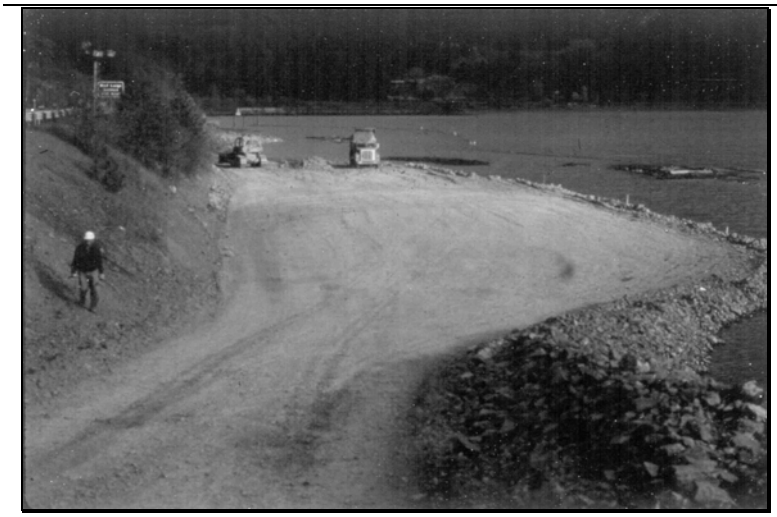


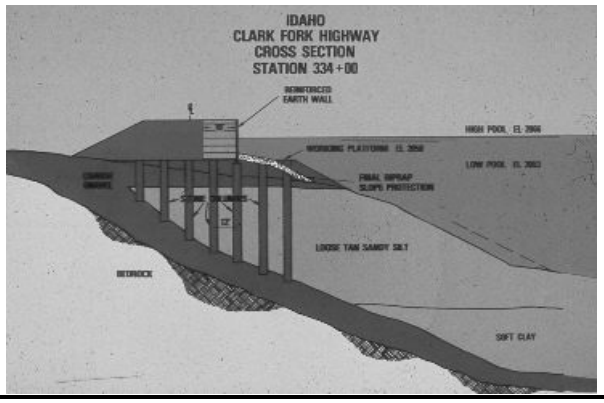
Slide 5-2-15

Ground Improvement

- ***Grouting***
- ***Vertical Wick Drains***
- ***Stone Columns***
- ***Vibro Compaction***
- ***Dynamic Compaction***
- ***Soil Mixing***
- ***Soil Nailing***
- ***Reinforced Soil Slopes***
- ***Micropiles***

Slide 5-2-16

Ground Improvement Stone Columns



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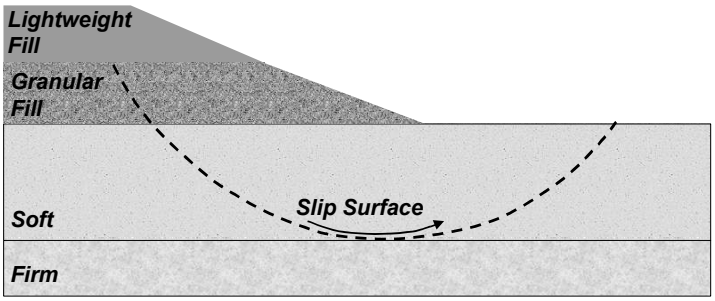
Lightweight Fill



Effect: Reduce Driving Weight

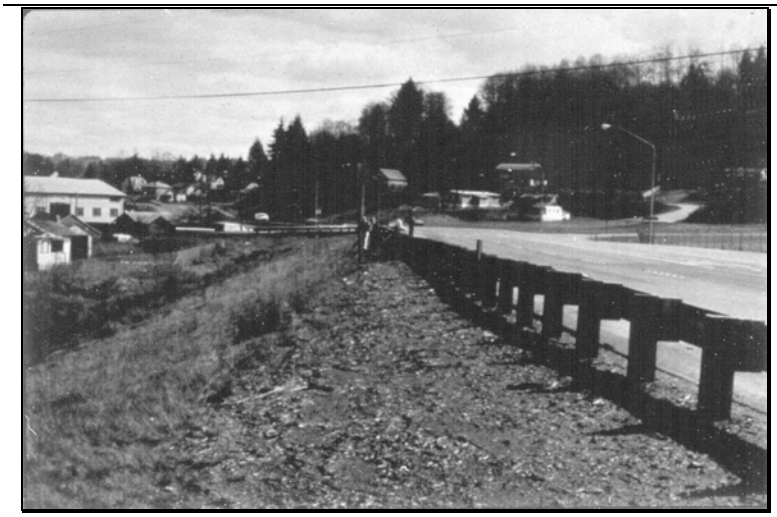
Slide 5-2-18

Examples of Lightweight Fill Materials

- ***Wood Fiber***
- ***Shredded Tires***
- ***EPS***

Slide 5-2-19

Slide 5-2-20



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Slide 5-2-24

Slide 5-2-25

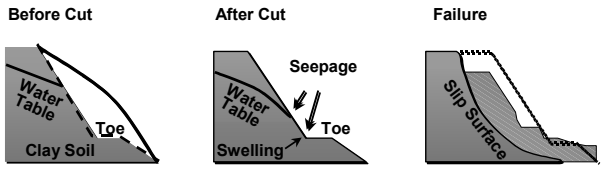
Slide 5-2-26

Cut Slope Stability

- ***Deep-Seated Failure (clays)***
- ***Shallow Surface "Sloughs" in Saturated Slopes of Clay, Silt and/or Fine Sand***

Slide 5-2-27

Cut Slope Stability



Undrained Clay in Cut Gradually Weakens And May Fail Long After Construction

Slide 5-2-28

Solutions to Cut Slope Stability Problems

- ***Flatten or Bench Slope***
- ***Buttress Toe***
- ***Lower Water Table***

Ground Improvement and Biotechnical Stabilization are also potential solutions.

Slide 5-2-29

Slide 5-2-30

Slide 5-2-31

Slide 5-2-32

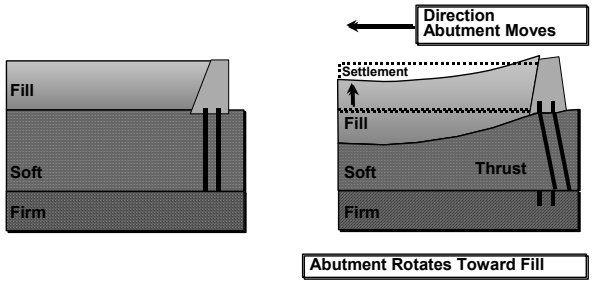
Cut Slopes

Minimum Recommended Safety Factor = 1.50

Cut Slopes may Deteriorate With Time as a Result of Natural Drainage Conditions That Embankments Do Not Experience

Slide 5-2-33

Lateral "Squeeze" of Soft Subsoil



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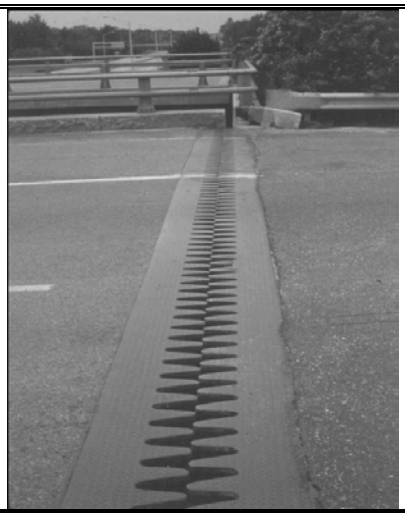


Slide 5-2-35

Slide 5-2-36

Lateral Squeeze: Abutment Rotation Can Occur if:

$$\gamma_{FILL} \times H_{FILL} > 3 \times \text{Cohesion}$$

Slide 5-2-37

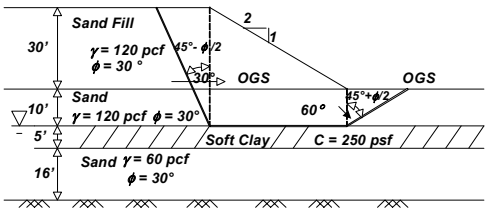
Lateral Squeeze: How to Prevent Abutment Rotation

Get Fill Settlement Out Before Abutment Piling are Driven

Slide 5-2-38

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 2
Sliding Block Analysis – Part 3



(3) Assuming the F.S., from Part 1, is less than acceptable, state 2 method(s) of making the slope safe.

Explain, with reference to the F.S. equation, why your method <u>increases</u> the factor of safety.

Slide 5-2-39

SOILS AND FOUNDATIONS WORKSHOP

SOLUTIONS TO SLOPE INSTABILITY

- ***Discuss Solutions to Stability Problems***

Activities: Stability Problem Solving

Slide 5-2-40

SOILS AND FOUNDATIONS WORKSHOP

Site Exploration

Basic Soil Properties

Laboratory Testing

Slope Stability

Circular Arc
Sliding Block
Lateral Squeeze

Embankment Settlement

Spread Footing Design

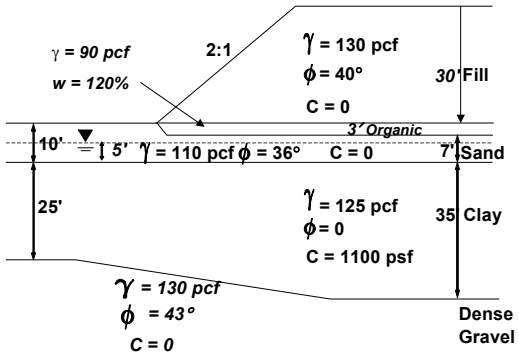
Pile Design

Construction Aspects

Slide 5-2-41

SOILS AND FOUNDATIONS WORKSHOP

WORKSHOP DESIGN PROBLEM
APPROACH EMBANKMENT STABILITY
DESIGN SOIL PROFILE



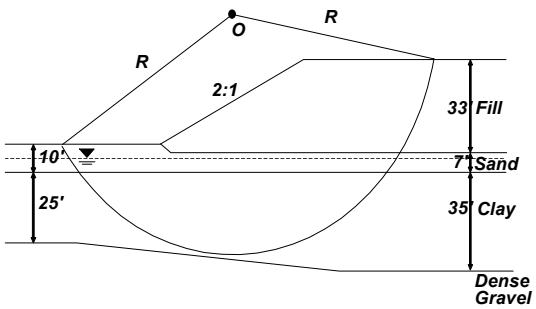
Estimate the safety factor and the need for a more detailed analysis.

Slide 5-2-42

SOILS AND FOUNDATIONS WORKSHOP

Compute F.S. Against Circular Arc Failure by

Normal Method (Hand Solution)



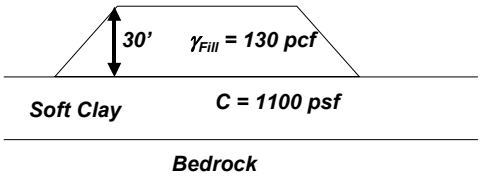
For deep clay subsoil the "critical" (Min. F.S.) failure surface will generally pass deep into the weakest clay layer. The center of the circle usually lies above the fill slope

Slide 5-2-43

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis Rule of Thumb for Factor of Safety

$$\text{Factor of Safety (F.S.)} = \frac{6C}{\gamma_{Fill} \times H_{Fill}}$$

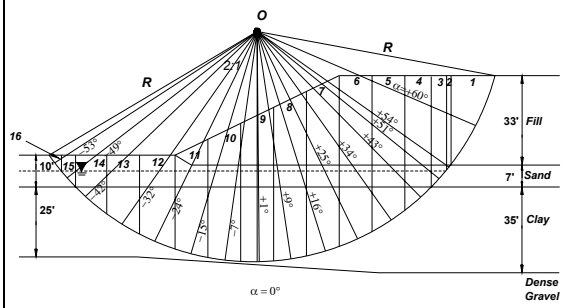


$$F.S. = \frac{(6)(1100)}{(130)(30)} = 1.69$$

Slide 5-2-44

SOILS AND FOUNDATIONS WORKSHOP

Compute F.S. Against Circular Arc Failure by Normal Method (Hand Solution)



Note that slices 1 through 9 have positive α angles and contribute to the driving force. Slices 10 through 16 have negative α angles and reduce the net driving force.

Slide 5-2-45

SOILS AND FOUNDATIONS WORKSHOP

Workshop Design Problem

Slice No.	W_T (lb)	l (ft)	α (deg)	c (psf)	φ (deg)	μ (psf)	μl (lb)	$W_T \cos\alpha$ (lb)	N (lb)	N Tan φ (lb)	Cl (lb)	T (lb)
1	32,175	36	60	0	40	0	0	16,088	16,088	13,499	0	27,864
2	8,800	3	54	0	36	0	0	5,173	5,173	3,758	0	7,119
3	19,140	7	51	0	36	150	1050	12,045	10,995	7,988	0	14,875
4	62,720	17	43	1100	0	-	-	-	-	0	18,700	47,549
5	83,790	15	34	1100	0	-	-	-	-	0	16,500	48,955
6	93,720	15	25	1100	0	-	-	-	-	0	16,500	39,608
7	95,790	13	16	1100	0	-	-	-	-	0	14,300	26,403
8	89,400	13	9	1100	0	-	-	-	-	0	14,300	13,985
9	80,760	12	1	1100	0	-	-	-	-	0	13,200	1,409
10	70,680	12	-7	1100	0	-	-	-	-	0	13,200	-8,614
11	59,350	13	-15	1100	0	-	-	-	-	0	14,300	-15,102
12	50,050	14	-24	1100	0	-	-	-	-	0	15,400	-20,357
13	36,450	14	-32	1100	0	-	-	-	-	0	15,400	-19,316
14	22,200	16	-42	1100	0	-	-	-	-	0	17,600	-14,855
15	3,300	6.5	-49	0	36	150	975	2,165	1,190	865	0	-2,491
16	1,100	6.5	-53	0	36	0	0	662	662	481	0	-878
										Σ 26,591	169,400	144,154

C = cohesion intercept
φ = friction angle
μ = pore pressure
W_T = total wt. of slice (soil + water)

$$F = \frac{\Sigma (W_T \cos\alpha - \mu l)\tan\phi + \Sigma cl}{W_T \sin\alpha}$$

$$F = \frac{\Sigma N \tan\phi + \Sigma cl}{\Sigma T} = \frac{26{,}591 + 169{,}400}{144{,}154} = \underline{1.36}$$

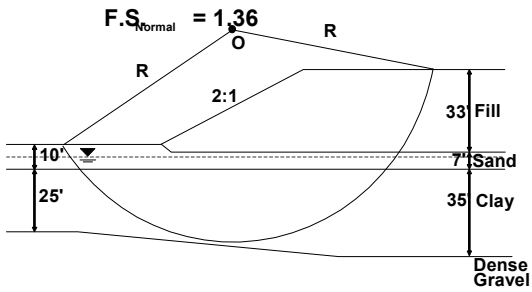
TABULAR FORM FOR CALCULATING F.S. BY NORMAL METHOD OF SLICES

Slide 5-2-46

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices

Hand Solution



Workshop Design Problem

APPLE FREEWAY - E. APPROACH EMB.

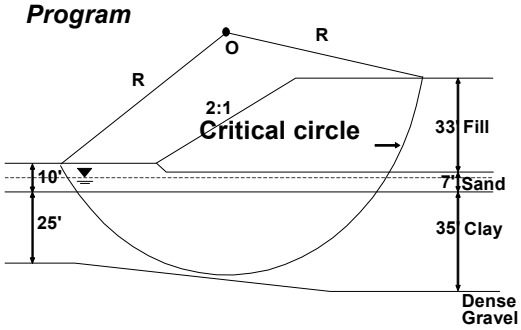
Slide 5-2-47

SOILS AND FOUNDATIONS WORKSHOP

Comparison of Factors of Safety

F.S. = 1.36 Normal Method - Hand Solution

F.S. = 1.63 Bishop Method - Computer Program



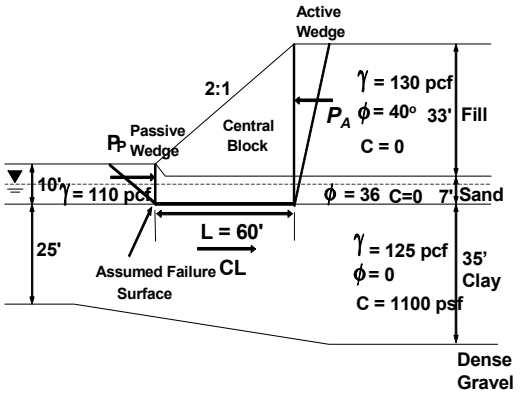
Remember the Normal Method is very conservative when the soil profile has frictional soil and the Bishop method is more theoretically correct.

Slide 5-2-48

SOILS AND FOUNDATIONS WORKSHOP

Sliding Block Analysis

Estimate F.S. Against Sliding Block Type Failure along top of Clay Layer for Assumed Failure Surface Shown.



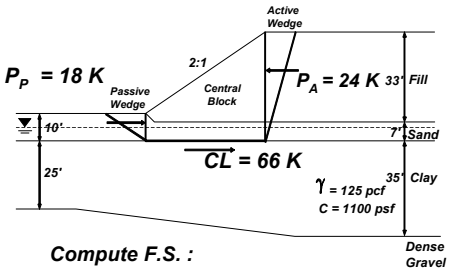
APPLE FREEWAY - EAST APPROACH EMB.

Slide 5-2-49

SOILS AND FOUNDATIONS WORKSHOP

Sliding Block Analysis

APPLE FREEWAY - E. APPROACH EMB.



Compute F.S. :

$$F.S. = \frac{\text{Horiz. Resisting Forces}}{\text{Horiz. Driving Forces}}$$

$$\frac{18\ K + 66\ K}{24\ K} = \frac{84\ K}{24\ K} = 3.5\ (O.K.)$$

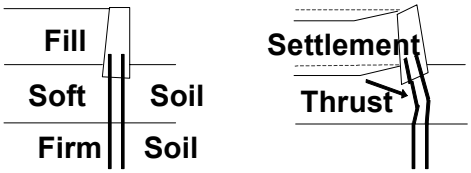
Circular Arc Failure More Critical

Slide 5-2-50

SOILS AND FOUNDATIONS WORKSHOP

Lateral Squeeze

Unbalanced fill load squeezes soil laterally.



Assumed ***Actual***

If $\gamma_{Fill} \times H_{Fill} > 3 \times Cohesion$

then lateral squeeze can occur.

Slide 5-2-51

SOILS AND FOUNDATIONS WORKSHOP

Lateral Squeeze

Apple Freeway - E. Approach Emb.

Lateral squeeze occurs if:

$\gamma_{Fill} \times H_{Fill} > 3 \times Cohesion$

For east abutment:

130 pcf x 30 ft > 3 x 1100 psf

3900 psf > 3300 psf

Lateral squeeze <u>can</u> occur

Don't construct abutment until settlement is complete (U90%).

Slide 5-2-52

SOILS AND FOUNDATIONS WORKSHOP

Embankment Stability

Design Soil Profile

Soil layer unit weights and strengths estimated

Circular Arc Analysis

Approach embankment safety factor 1.63 against circular failure

Sliding Block Analysis

Approach embankment safety factor 3.5 against sliding failure

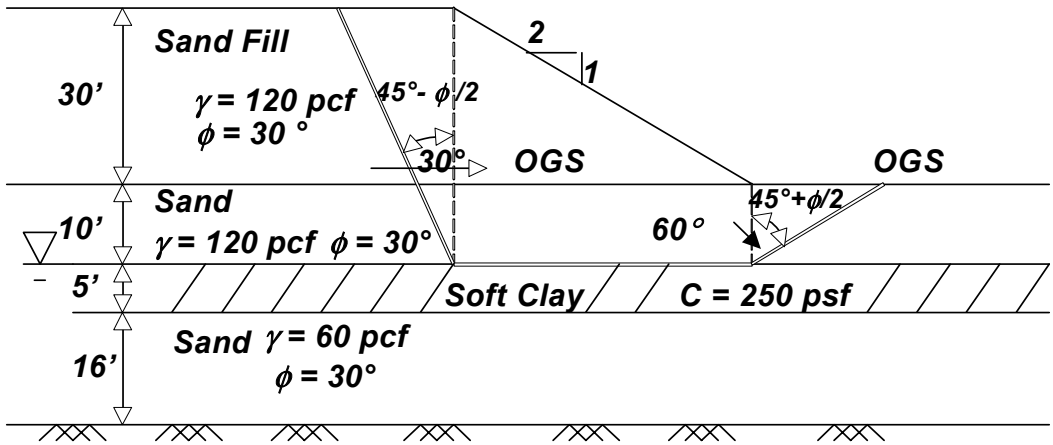
Lateral Squeeze

Possible abutment rotation

Slide 5-2-53

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 2
Sliding Block Analysis – Part 3



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