LESSON 5

TOPIC 2

Solutions to Slope Instability

SOLUTIONS TO SLOPE INSTABILITY

Lesson 5 - Topic 2

Slide 5-2-1

The question to pose to the students now is “What do we do if we detect a potential stability problem?” Name some potential solutions to slope stability problems.

SOLUTIONS TO SLOPE INSTABILITY

1. Discuss Solutions to Stability Problems

ACTIVITIES: Stability Problem Solving

Slide 5-2-2

State objective. Alert students that the activity will be to suggest solutions to stabilize the embankment in the previous sliding block exercise.

Solutions to Slope Stability Problems

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

Slide 5-2-3

Introduce methods of solution for stability problems. Mention to the students that you will present examples for all these treatments except change of alignment (which you should briefly discuss while this slide is on the screen).

In every example (except change of alignment where no example will be discussed) stress that either resisting or driving forces are affected by the remedial treatment.

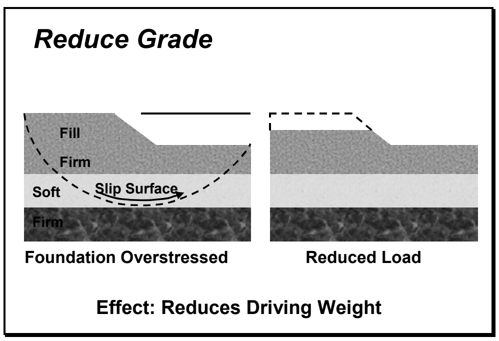
Use schematics to permit understanding of stabilization concepts. Use case histories to show real life treatment procedures. Local case histories may be substituted as desired for the examples that follow.

Solutions to Slope Stability Problems (Cont'd)

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

Slide 5-2-4

Continue with methods of solution for stability problems. In every example stress that either resisting or driving forces are affected by the remedial treatment. Use schematics to permit understanding of stabilization concept and case histories to show real life treatment procedure. Local case histories may be substituted as desired for the examples.



Slide 5-2-5

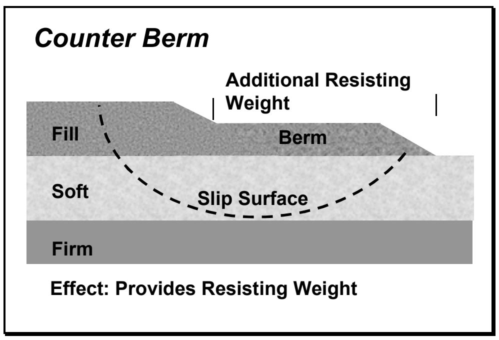
Reducing the grade reduces the driving force.

Slide 5-2-6

This case history involves an embankment failure adjacent to a railroad. Note the heave of the ground and the railroad bed. Note the misalignment of the tracks that caused the speed of the trains to be reduced to 5 mph in this area. A fast solution was needed to permit the railroad to realign the tracks and restore normal services.

Slide 5-2-7

Discussions with the roadway designer indicated that the original grade of the ramp had been raised to accommodate the placement of excess project materials. The grade was subsequently lowered to the original elevation and the slope movement stopped.

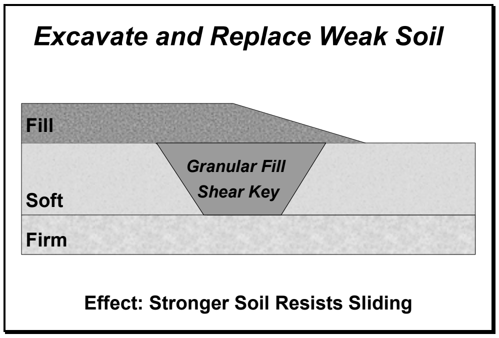


Slide 5-2-8

The berm solution adds weight to the resisting side of the center of the circle. This weight will increase the resisting forces and may reduce the net driving force for original critical failure surfaces. The most critical failure surface is changed by placement of the counter berm. The new critical surface should exit beyond the toe which results in an increase in resistance.

Slide 5-2-9

This counter berm is placed at the toe of slope and is composed of rock. Note that the length and height of the berm must be designed. Also the unit weight assumed for the berm in designed must be checked in construction.

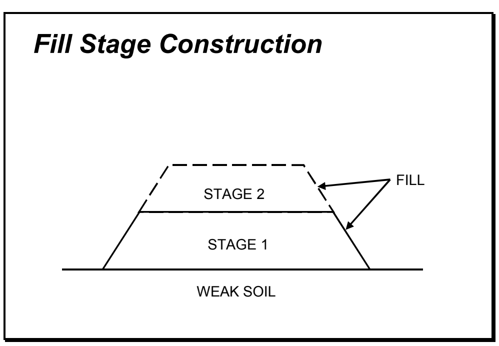


Slide 5-2-10

The shear key treatment involves the removal of soft soils and replacement with granular soils generally in an area under the slope of a planned embankment. The key generally is excavated to the full depth of the soft soil and "keyed" into the underlying firm soil. The later placement of the embankment will cause increased normal forces in the shear key and therefore increased shear strength to resist failure through the shear key.

Slide 5-2-11

This shear key is under construction in an excavated trench. Note that rock is the preferred material to use in a shear key due to good frictional properties and ease of placement in a confined, often wet, area.

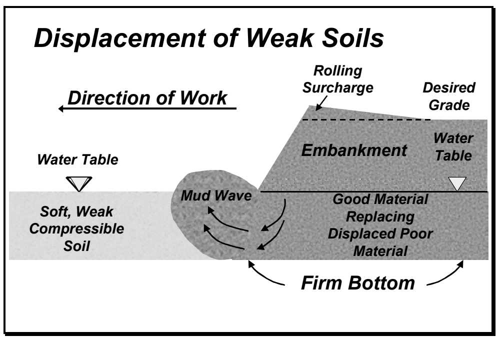


Slide 5-2-12

Stage construction of fills is usually done over soft soils that will exhibit strength gain with time due to the increased load. The objective is to increase the resisting force in the soft soil. The designer uses soil test data to determine the initial height of fill that can be safely placed over the soft soil. Then the designer determines the strength gain in the soft soil that will occur with consolidation under the initial fill. The designer then determines how much additional fill can be placed for the increased foil strength. Often several stages of placement are needed to achieve final grade.

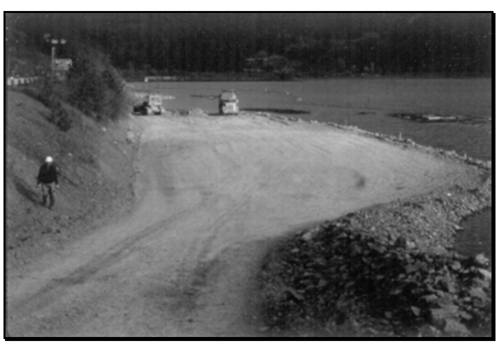
Slide 5-2-13

Stage construction should always be monitored with geotechnical instrumentation to insure that the consolidation is occurring in the soft soil as planned and that the fill height rate of placement is acceptable.



Slide 5-2-14

Displacement of soft soils is accomplished by purposely building the fill to such a height that a controlled shear failure occurs. This procedure increases the resisting forces as the embankment material replaces the soft soils. The fill is slowly advanced in one direction to cause complete displacement of the soft soil. The mud wave that occurs at the leading edge of the fill must removed to prevent soft material from becoming entrapped under the advancing fill.



Slide 5-2-15

This displacement project in Idaho involved a fill construction over very soft soils in a lake. Note the mud waves occurring in the lake. These mud waves had to be removed as they surfaced to prevent trapping soft soil under the fill.

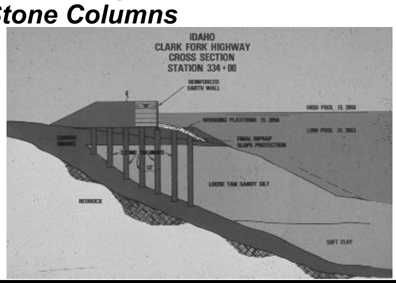
Ground Improvement

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

Slide 5-2-16

Briefly describe the basic concepts associated with each method. Recommend FHWA Demo 116, Ground Improvements for detailed information on these methods.

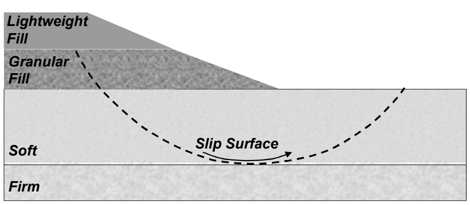
Ground Improvement
Stone Columns



Slide 5-2-17

One example of ground improvement is the Clark Fork Highway in Idaho. The original design involved a long sliver fill that extended far into the lake and resulted in low design safety factors. The use of MSE wall reduced the required embankment cross section. The use of stone columns ensured the safety factor and supported the MSE wall and side slope.

Lightweight Fill



Effect: Reduce Driving Weight

Slide 5-2-18

The use of lightweight filling materials reduces the driving force. The materials used in this method are numerous. Important factors to consider in the use of lightweight materials are cost, placement, availability, density, and environmental effect.

Examples of Lightweight Fill Materials

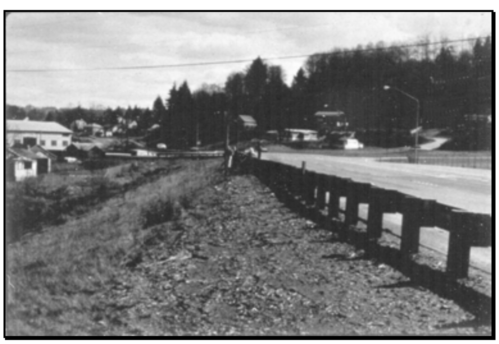
- ***Wood Fiber***
- ***Shredded Tires***
- ***EPS***

Slide 5-2-19

These three materials have been used in highway applications as lightweight materials and will be discussed further. Many other lightweight materials have been used but are beyond the scope of this class. More information can be found in FHWA Demonstration Project 116, publication FHWA-SA-98-086.

Slide 5-2-20

Typical wood fiber project in the Northwest US. Note that materials are spread and compacted with a dozer. Several types of wood fibers are used for fills including sawdust, wood chips, and hog fuel.



Slide 5-2-21

This is a completed view of a wood fiber embankment. Case history data: originally 10' of asphalt pavement by the maintenance to correct settlement problems. Note that the exterior of the wood fiber has been covered with an emulsion, fine-grained soil and vegetation. Experience with uncovering old fiber fills shows that only the exterior of the fiber fill decomposes and creates a "seal" for the interior.


Slide 5-2-22

This shredded tire project in Virginia. Note the tires are delivered to the site and stockpiled. Spreading and compaction is done with tracked equipment as the steel belts can cause significant damage to rolling construction equipment. On this project the shredded tires were placed in alternating layers with soil.


Slide 5-2-23

Note the size of the tire shreds are fairly large. After compaction of the shreds, a soil cover of at least 4' is placed between the shreds and the pavement section.


Slide 5-2-24

EPS (Expanded Polystyrene), which is also known as Geofoam, is an ultra light weight material. Even the instructor could easily lift a 32 cubic foot block of EPS. (This block only weighed about 40 pounds).

Slide 5-2-25

Construction with EPS only requires basic tools such as a chain saw to trim the block to the desired shape.

Slide 5-2-26

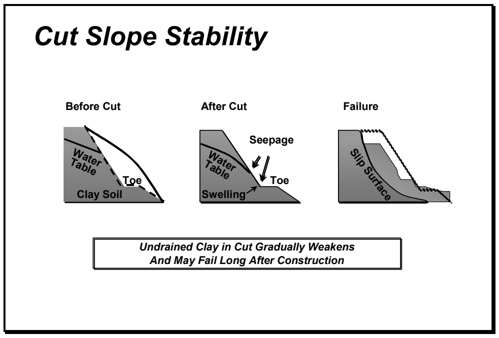
The assembly of the EPS fill occurs quickly as the block are placed in an interlocking pattern and anchored to the previous row with timber hooks. This installation on the I-15 Salt Lake City Project was used as an approach embankment.

Cut Slope Stability

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

Slide 5-2-27

Introduce cut slope stability.



Slide 5-2-28

Explain the effect of water on long term cut stability. Remind students of what happens in the lab when a clay sample is taken out of the tube and allowed to expand. Focus on the clay swelling, absorbing more water, and the strength decrease with time.

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

The first three solutions are the bread and butter solutions used by highway agencies. The latter two solutions are methods that may require specialists for both the design and construction of the solution.

Slide 5-2-30

Show case history of cut stabilization. This is a typical springtime “pop-out” caused by fine-grained soils and a high water table. The soil becomes nearly quick and slides into the ditch. Tell the group that the wrong solution is to simply have maintenance push this material back up the slope. Then ask the audience what their agency does to remedy these problems?

Slide 5-2-31

Mention that the most common solution to the problem is to remove the wet material. Then construct a shallow (4' by 4') rock key at the toe and replace the wet material with rock that is pushed up the slope with a dozer. Note that the dozer will compact the material during the placement.

Slide 5-2-32

Note that the rock key at the toe is absolutely necessary to provide a base to prevent the rock from slipping back down slope due to erosion at the toe. Generally a 4' wide by 4' deep key is constructed beneath the foot of toe.

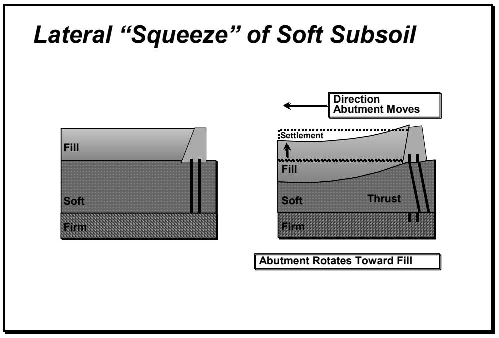
Cut Slopes

Minimum Recommended Safety Factor = 1.50

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

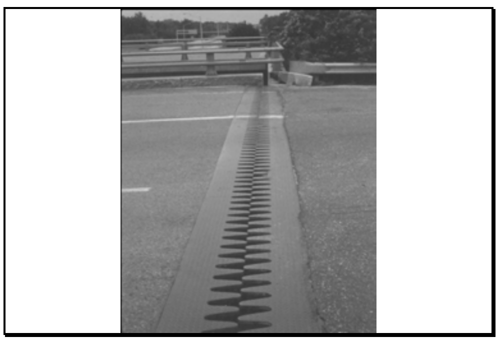
Slide 5-2-33

Explain the need for a higher safety factor for cut slopes.



Slide 5-2-34

Introduce lateral squeeze. Explain that lateral squeeze most commonly occurs in soft ground conditions when a fill is constructed behind a structure on a deep foundation. The fill tends to settle non-uniformly and cause the soft soil to be squeezed toward the foundation. Normally the foundation elements are so close that the soil cannot flow in between. High forces develop on the foundation, which result in movement of the structure. The instructor should comment on the large magnitude of the forces as non-geotechnical engineers commonly misunderstand this concept.



Slide 5-2-35

Show lateral squeeze case history. Begin by noting that the open joint seems a bit unusual as this picture was taken in the middle of the summer. Then point out the far wingwall distortion and ask what is happening? Then show next slide of severe distortion under abutment.

Slide 5-2-36

Show lateral squeeze case history. Note the backward rotation of the abutment has caused the beams to nearly fall off the rockers. Then ask how we could have mitigated this movement.

Lateral Squeeze: Abutment Rotation Can Occur if:

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

Slide 5-2-37

Explain the limiting condition for occurrence of lateral squeeze.

Lateral Squeeze: How to Prevent Abutment Rotation

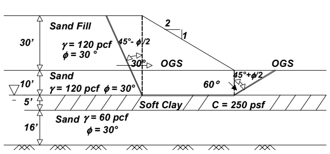
Get Fill Settlement Out Before Abutment Piling are Driven

Slide 5-2-38

Lateral squeeze solution.

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise No. 2
Sliding Block Analysis – Part 3



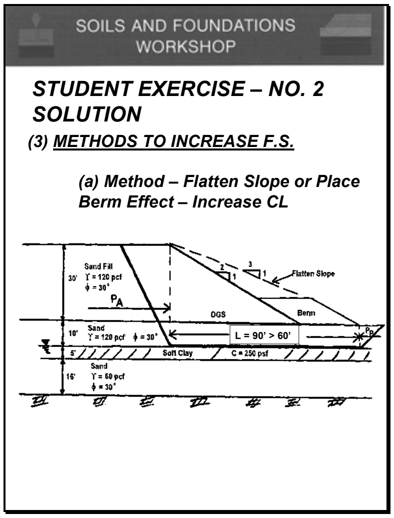
(3) Assuming the F.S., from Part 1, is less than acceptable, state 2 method(s) of making the slope safe.

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

Slide 5-2-39

GROUP EXERCISE After slide presentation on solutions; ask group to apply the knowledge to the previous student exercise for the sliding block. Get the students to focus on changes that occur to the driving and resisting forces for the solutions that they chose. GROUP EXERCISE

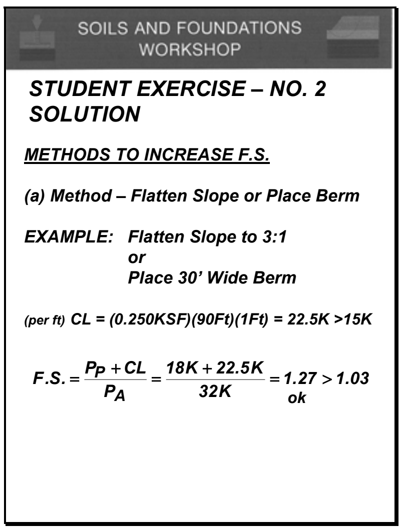
Please refer to the end of the lesson for this exercise.



Slide 5-2-40

Ask secondary questions about solutions; i.e., for berm: ask group how important is compaction, how is berm height determined, and how should berm surface be graded? Compaction must insure that the design density was achieved. Berm height is determined by the height needed to prevent the failure from exiting through the berm rather than forced out beyond the berm and the stability of the berm may need to be checked. Berm surface should be graded to prevent water form ponding at the embankment interface with the berm.

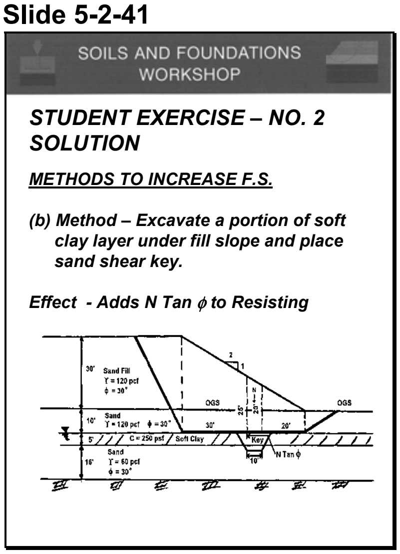
Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 5-2-41

Ask secondary questions about solutions; i.e., berm ask how important is compaction, how is berm height determined, and how should berm surface be graded? Compaction must insure that the design density was achieved. Berm height is determined by the height needed to prevent the failure from exiting through the berm rather than forced out beyond the berm and the stability of the berm may need to be checked. Berm surface should be graded to prevent water form ponding at the embankment interface with the berm.

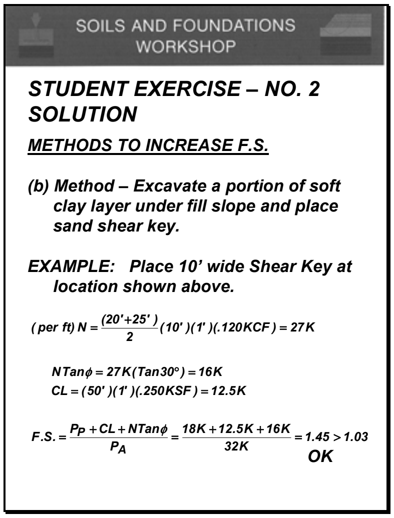
Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 5-2-42

For shear key ask what is minimum width determined by and where is optimal location for key? Minimum width is determined by both the design analysis and by the equipment that will construct the key. Commonly a key is constructed with a dozer and the key width will be at least the width of the blade, I.e., about 10'.

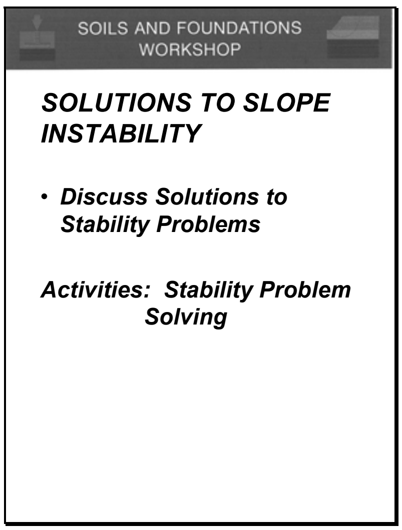
Please refer to the end of the Participant Workbook for the solution to this exercise.



Slide 5-2-43

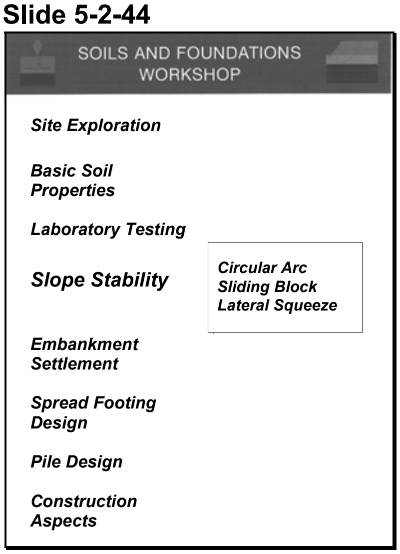
For shear key ask what is minimum width determined by and where is optimal location for key? Minimum width is determined by both the design analysis and by the equipment that will construct the key. Commonly a key is constructed with a dozer and the key width will be at least the width of the blade, i.e., about 10’.

Please refer to the end of the Participant Workbook for the solution to this exercise.



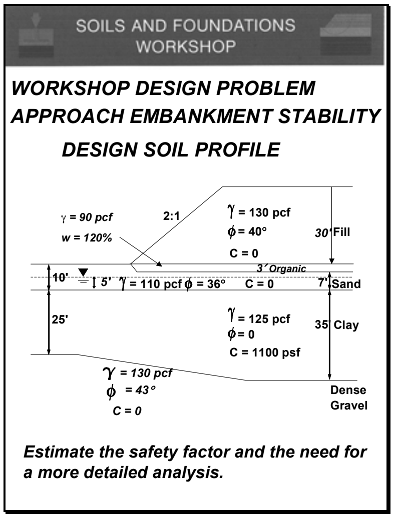
Slide 5-2-44

Review objective for Topic 2. Then go to reference manual and review the sections covered in Topic 2. Then begin the Apple Freeway problem.



Slide 5-2-45

Review data gathering phases for Apple Freeway. Note the first step in design is to assure stability of the embankment.



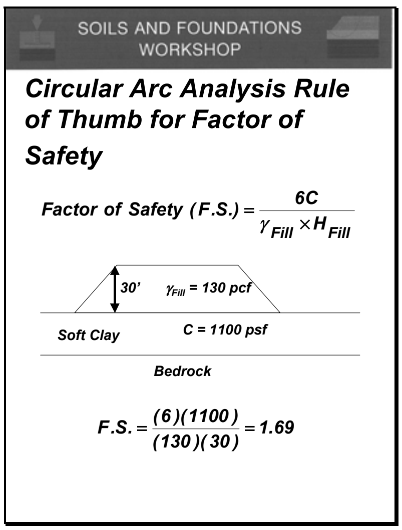
Slide 5-2-46

Use the Apple Freeway to test knowledge of slope stability concepts and solutions.

What type of failure would you expect at this site?

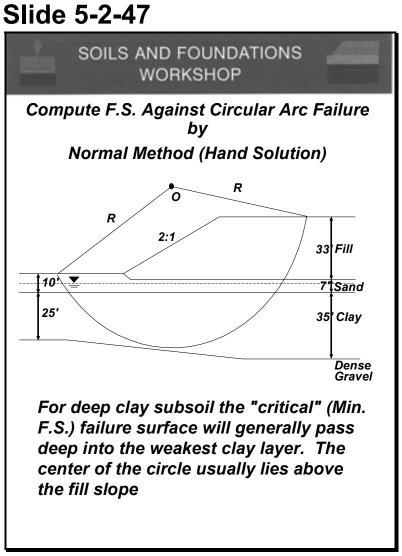
Should you excavate the organic material?

If you do excavate how could you estimate the factor of safety quickly from this profile, and the need for a more detailed analysis?



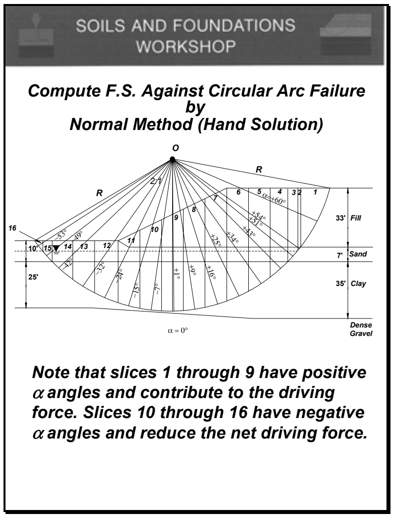
Slide 5-2-47

The answer to the previous question is use the rule of thumb. This computation is shown in the reference manual, page 5-5. If the safety factor is less then 2.5, a more sophisticated analysis is required.



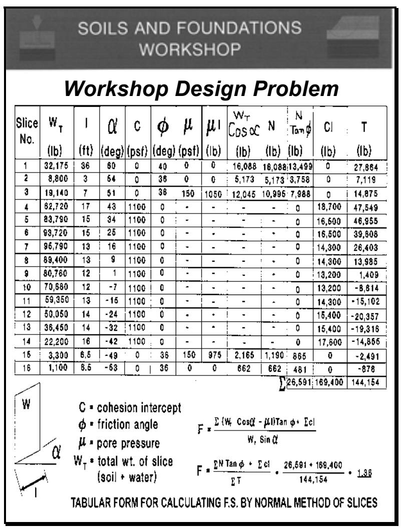
Slide 5-2-48

Discuss the reason the trial circle goes to the soft layer base.



Slide 5-2-49

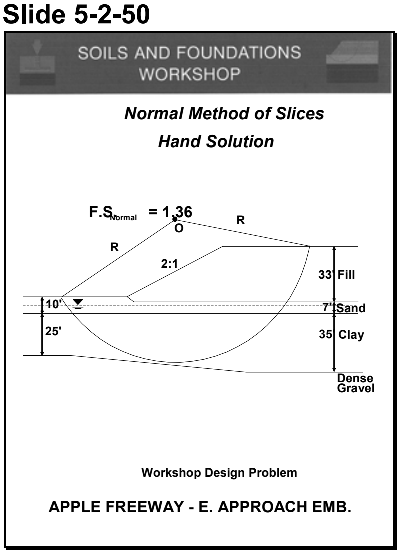
Discuss how rays (radius) are drawn from the circle center to the centroid of the base of each slice.



Slice No.	W_T (lb)	l (ft)	α (deg)	c (psf)	φ (deg)	μ (psf)	μl (lb)	W_T Cos α (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	46,955
6	93,720	15	25	1100	0	-	-	-	-	0	16,500	39,608
7	96,790	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

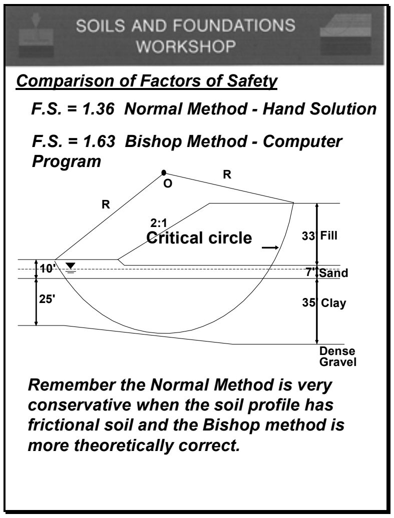
Slide 5-2-50

Show the hand solution and comment on the time for one computation. Note the magnitude of the resisting and overturning forces are computed in the design analysis for a 1' wide slice and that most slides are hundreds of feet wide.



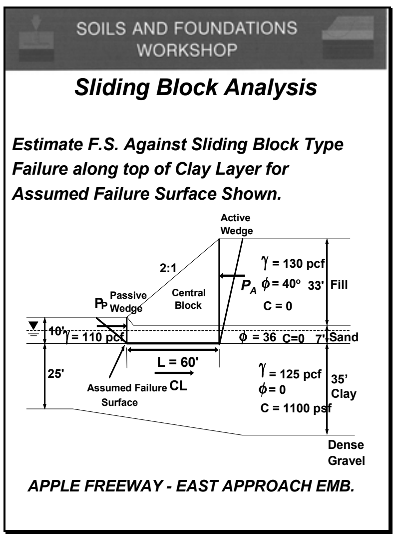
Slide 5-2-51

Discuss the computed safety factor versus what is required for this site.



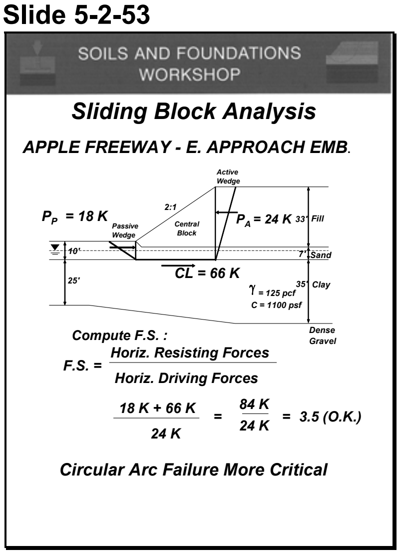
Slide 5-2-52

Discuss how different analyses produce different safety factors and ask which to use.



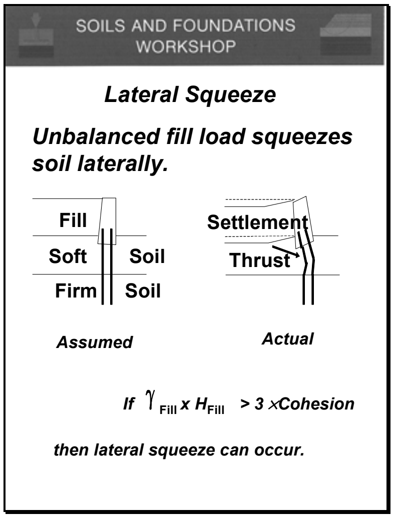
Slide 5-2-53

Ask if we would expect conditions to be favorable for a sliding block failure at this site.



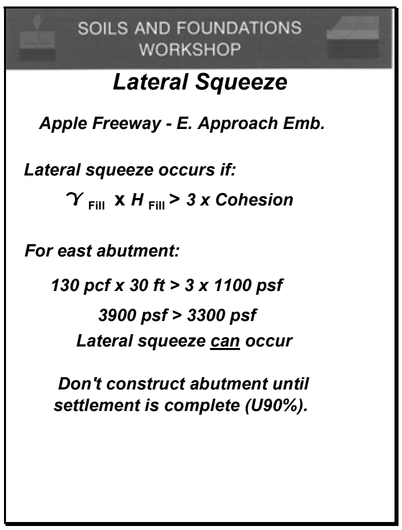
Slide 5-2-54

Show safety factor and ask if this is a critical failure mechanism for this site.



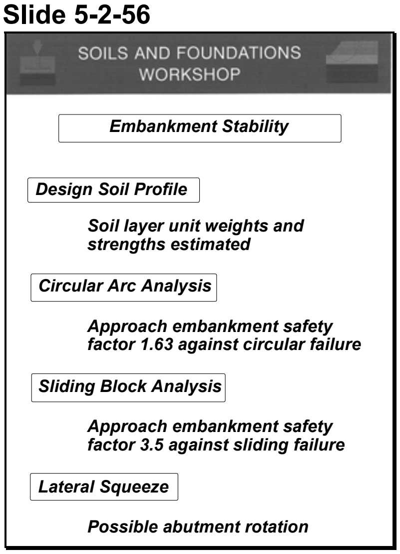
Slide 5-2-55

Ask how to determine if lateral squeeze is a problem at this site?



Slide 5-2-56

Explain lateral squeeze concept and application to Apple Freeway.



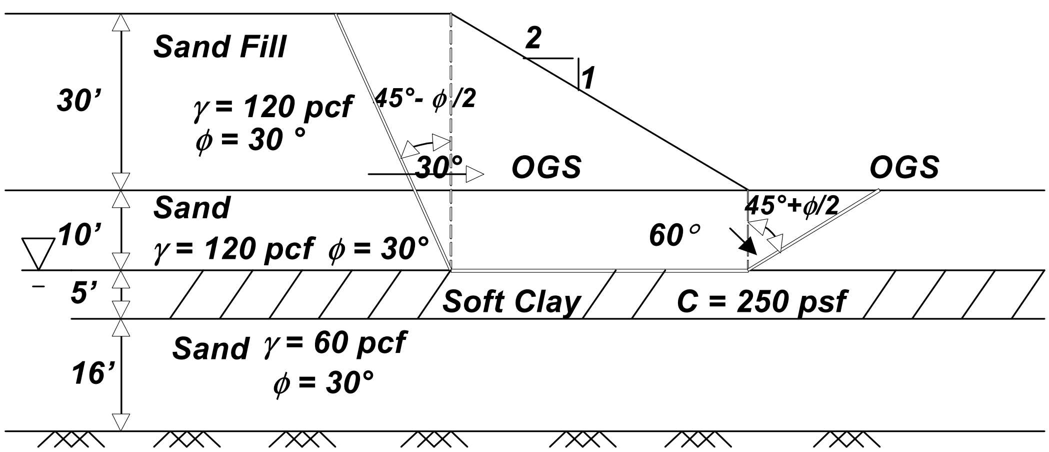
Slide 5-2-57

Review Apple Freeway accomplishments.

Instructor promotes NHI Slope Stability course.

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.

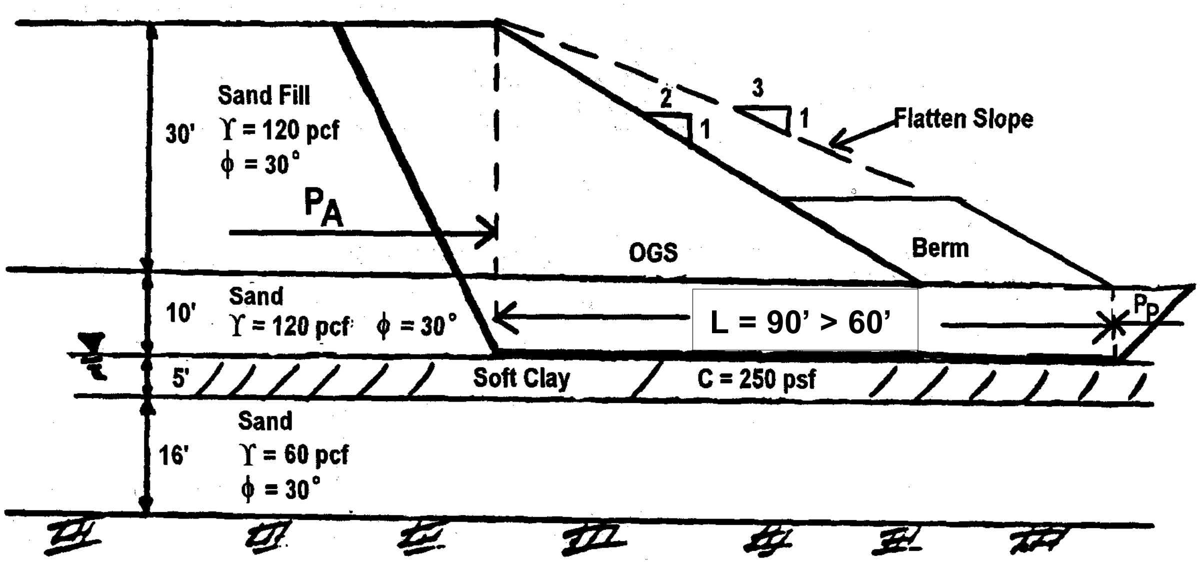
Explain, with reference to the F.S. equation, why your method <u>increases</u> the factor of safety.

SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE – NO. 2 SOLUTION

(3) METHODS TO INCREASE F.S.

(a) Method – Flatten Slope or Place Berm Effect – Increase CL



SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE – NO. 2 SOLUTION

METHODS TO INCREASE F.S.

(a) Method – Flatten Slope or Place Berm

EXAMPLE: ***Flatten Slope to 3:1***
or
Place 30' Wide Berm

(per ft) ***CL = (0.250KSF)(90Ft)(1Ft) = 22.5K >15K***

$$F.S. = \frac{P_P + CL}{P_A} = \frac{18K + 22.5K}{32K} = 1.27 > 1.03$$

ok

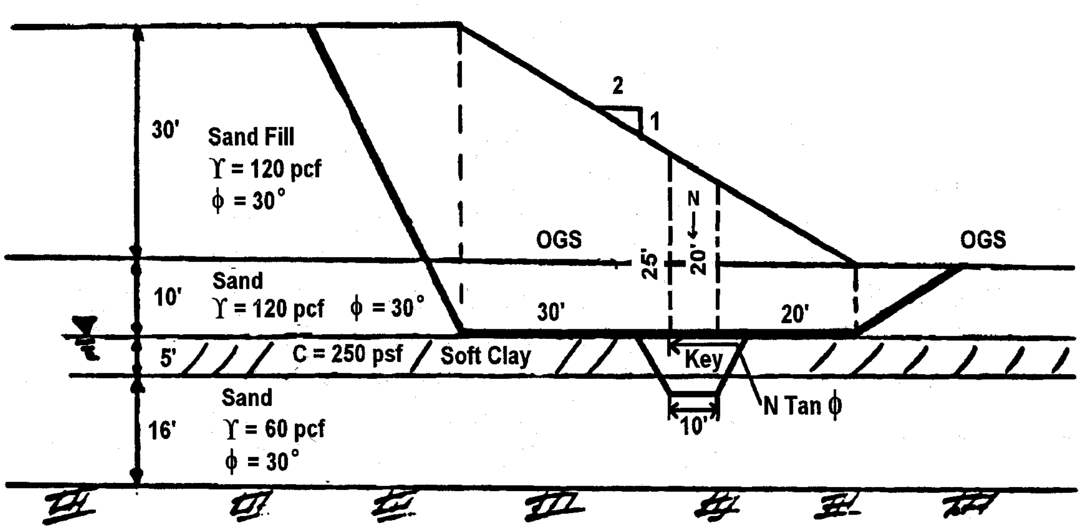
SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE – NO. 2 SOLUTION

METHODS TO INCREASE F.S.

(b) Method – Excavate a portion of soft clay layer under fill slope and place sand shear key.

Effect - Adds N Tan ϕ to Resisting



SOILS AND FOUNDATIONS WORKSHOP

STUDENT EXERCISE – NO. 2 SOLUTION

METHODS TO INCREASE F.S.

(b) Method – Excavate a portion of soft clay layer under fill slope and place sand shear key.

EXAMPLE: Place 10' wide Shear Key at location shown above.

$$(\text{per ft})\ N = \frac{(20' + 25')}{2}(10')(1')(.120KCF) = 27K$$

$$N\,Tan\phi = 27K(Tan30^\circ) = 16K$$

$$CL = (50')(1')(.250KSF) = 12.5K$$

$$F.S. = \frac{P_P + CL + N\,Tan\phi}{P_A} = \frac{18K + 12.5K + 16K}{32K} = 1.45 > 1.03$$

OK