Ground Control at Surface Mines

Spoil Pile Safety

Dump Points

Valley Fills

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Objectives

- Discuss some of the commonly used terminology which often results in confusion.
- Identify the hazards associated with spoil deposition and show some examples.
- Explain the underlying engineering concepts involved.
- Discuss how to identify and remedy spoil hazards

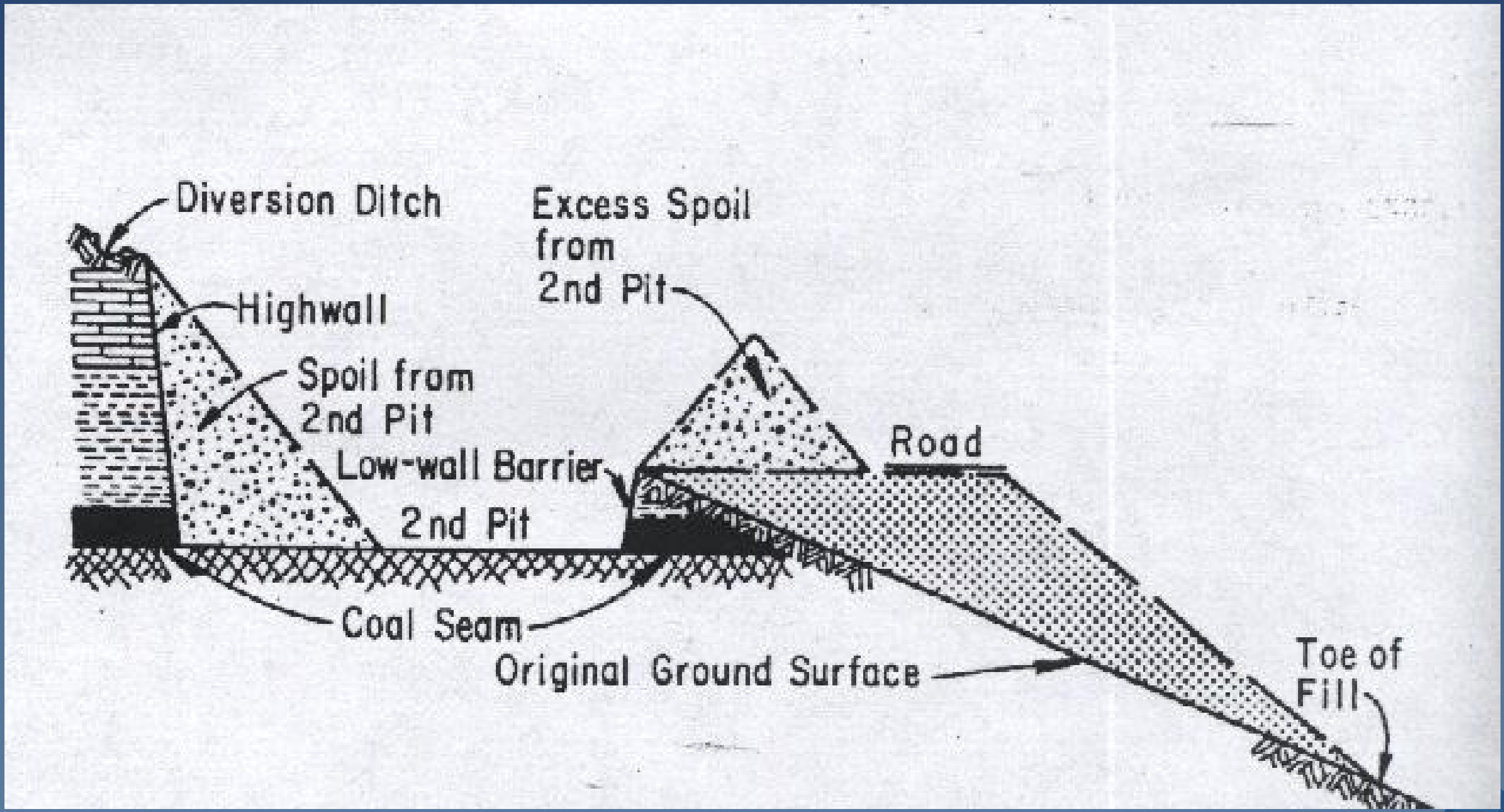
Terminology

- Highwall
- Lowwall
- Spoil
- Gradation
- Granular
- Cohesive
- Apparent Cohesion
- In-Place Rock
- Shot Rock (not unconsolidated material)
- Angle of Repose

- **Highwall** - The unexcavated face of exposed overburden and coal.
- **Spoil** – Overburden or other waste material removed during mining.

- **Lowwall:** An unexcavated face of overburden and coal directly across the pit from the highwall.

Highwall, Spoil Bank, Lowwall



Spoil Composition

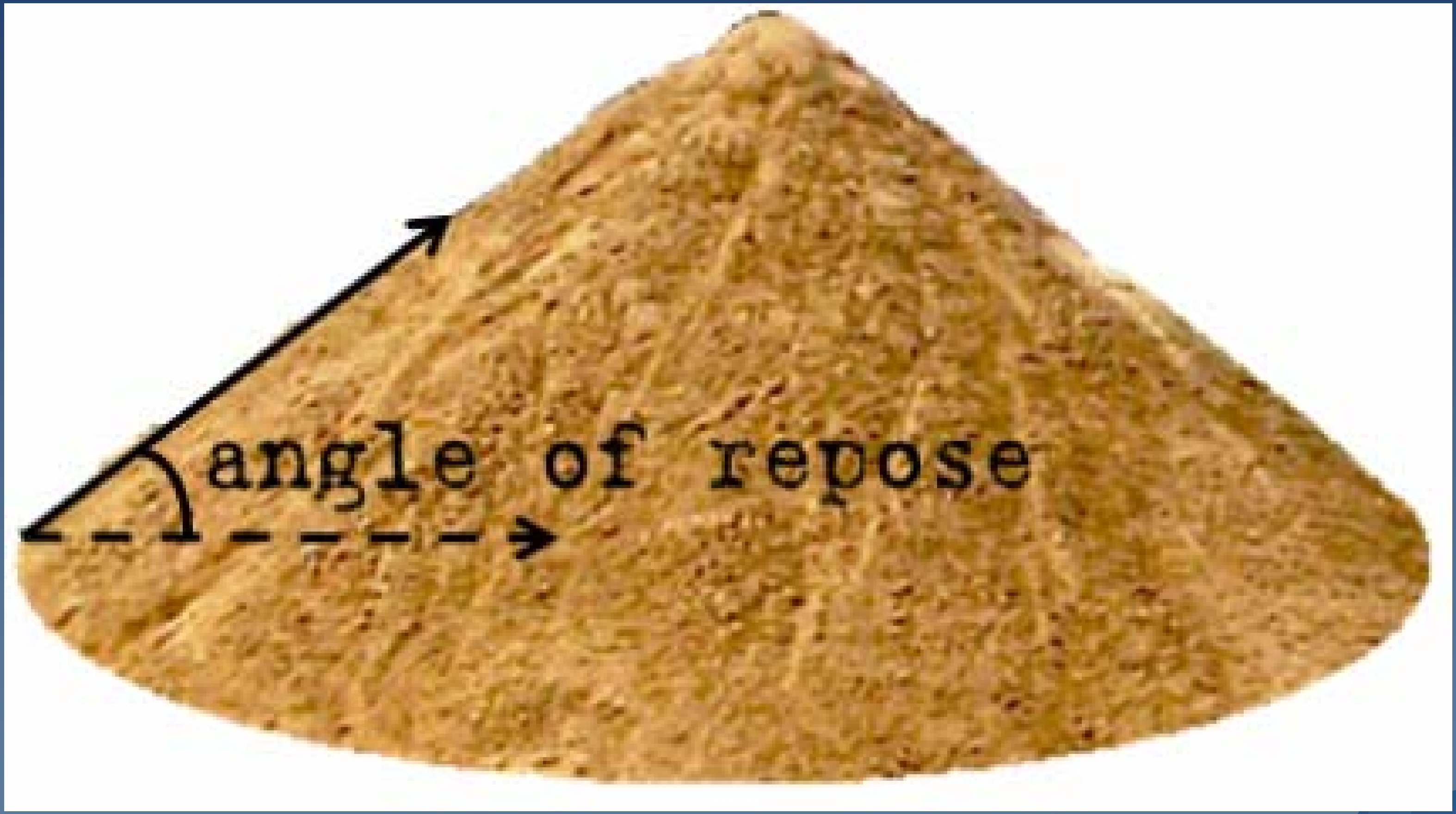
- Spoil consists of soil, shot rock, or more commonly, a mixture of both
  - **Gradation – distribution of material sizes in the mix.**
  - **Granular Material** - material such as shot rock, gravel, and sand, where the strength depends on the interlocking of particles and the friction between them.
  - **Cohesive Material** – clays - strength depends on “stickiness”, which on a particle level is the electrical attraction between microscopic particles.

Granular Material

Cohesive Material

- In-Place Rock – Rock in a highwall or lowwall which may have natural joints and fractures, but has not been significantly disturbed by blasting.
- Shot Rock – Rock which has been shot in place but has not yet been excavated.
- Unconsolidated Material?

Angle of Repose



Angle of Repose

- The angle that a dry, granular, material in a very loose condition will form with respect to the horizontal.

- In a practical sense, it is the angle that spoil will assume when dumped loosely into place.

Angle of Repose

- The angle of repose depends on characteristics of the material.
  - Roundedness or angularity of particles
  - Gradation
  - Surface roughness
- Typical Range
- Can materials stand steeper than their angles of repose?

Apparent Cohesion

Apparent Cohesion

- The phenomenon where a moist sandy material can be held in this position by the tension of the water in its pores.
- This is a temporary condition which can change if the material dries out or becomes fully saturated, and should not be relied upon when the safety of miners is involved.

Temporary Stability HAZARD


9 30 '99


STOP

Spoil Slope Hazards

- Material falling or rolling from pile.
- Slope Failures Affecting Pit.
- Slope failures under equipment.
  - Loss of dump point support
  - Foundation failure under dragline

Rock Falls

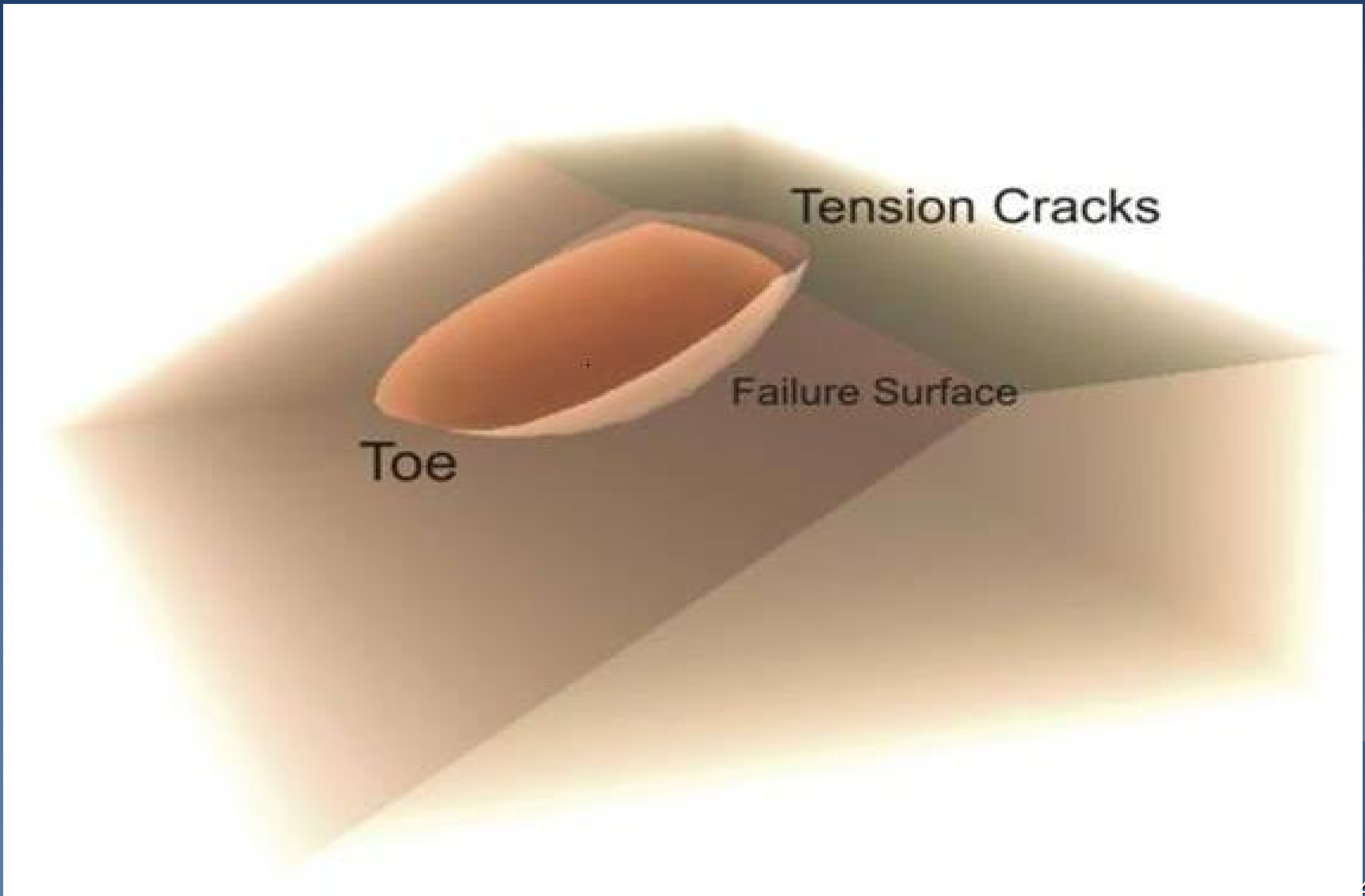
- Individual rocks are not likely to fall from a spoil bank inclined at the angle of repose or flatter except in very specific situations. Factors which need to be considered are:
  - Size and shape of rock
  - Nature of the spoil slope surface
  - Factors to initiate failure – e.g. Erosion of support
- If significant quantities of rocks are falling and accumulating at the base of the spoil bank, it is probably steeper than the angle of repose and you may have more serious problems.

Slope Stability Analysis

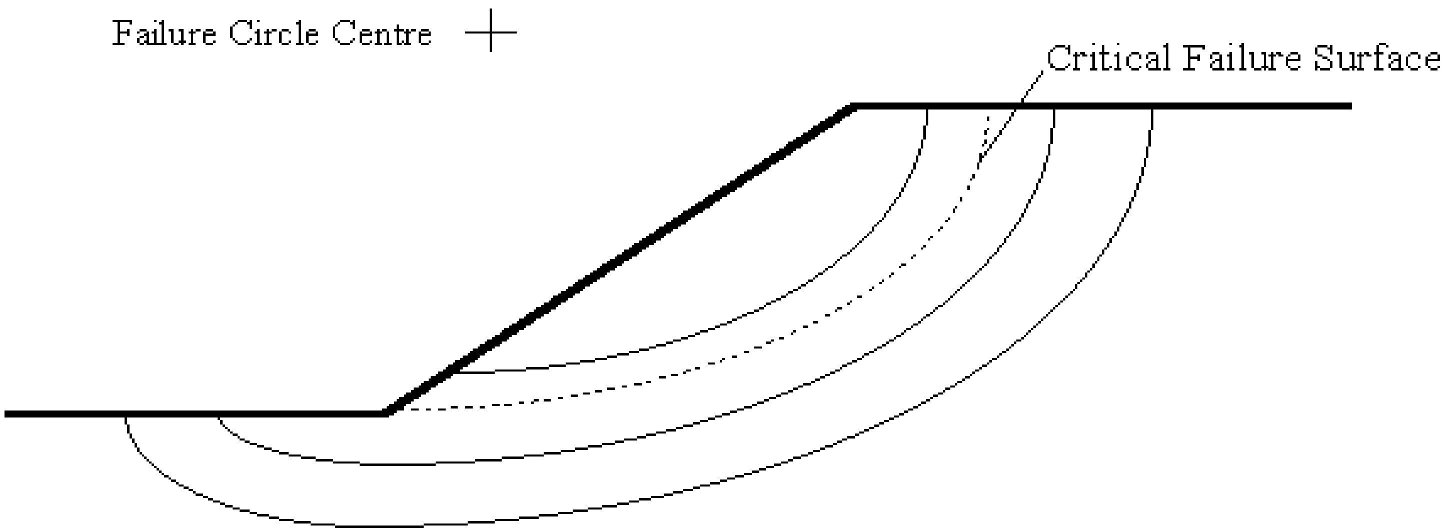
- An engineering method to quantify “how stable” a slope is.

- A way to determine and evaluate the factors that may cause a stable slope to become unstable, so that failure can be prevented.

Spherical Slope Failure



Variety of Slope Failure Circles Analysed at Varying Radii from a Single Circle Centre.



Factor of Safety

- Can be defined as the ratio of resisting forces to driving forces:

$$\text{Factor of Safety} = \frac{\text{Resisting Forces}}{\text{Driving Forces}}$$

Factors of Safety

- Slopes designed for long-term stability, like dams and important highway embankments are generally designed for FS = 1.5 to account for uncertainties in material strengths and fluctuating water conditions.

- A factor of safety of 1.5 means that the strength is 50% higher than the stress on the slope.

- A slope at the angle of repose has a Factor of Safety of 1.0. Meaning that there is just enough strength to keep the slope stable. It is exactly on the verge of failure.

- If we knew all of the conditions perfectly, a factor of safety of 1.0 would be adequate, but there is always a high level of uncertainty with the behavior of soil and rock.

- Active mining slopes are generally designed for lower factors of safety due to their temporary nature and frequent observation and inspection. But this means that there is less room for error.

Forces influencing embankment stability

- Factors Driving Failure
  - Gravity
  - Loading at the top
  - Removing support from the bottom (trimming toe of slope)
  - Changes in moisture conditions

- Factors Resisting Failure – Spoil Strength
  - Frictional forces
  - Cohesive forces
  - Strength can decrease due to locked-in water pressure.

Shear Strength of Spoil

- Depends on **friction** between particles and **cohesion**. Spoil will typically have strength from both. (Expressed as engineering parameters C and ϕ).

- Can be estimated from field observations and/or Laboratory tests.

Granular Material

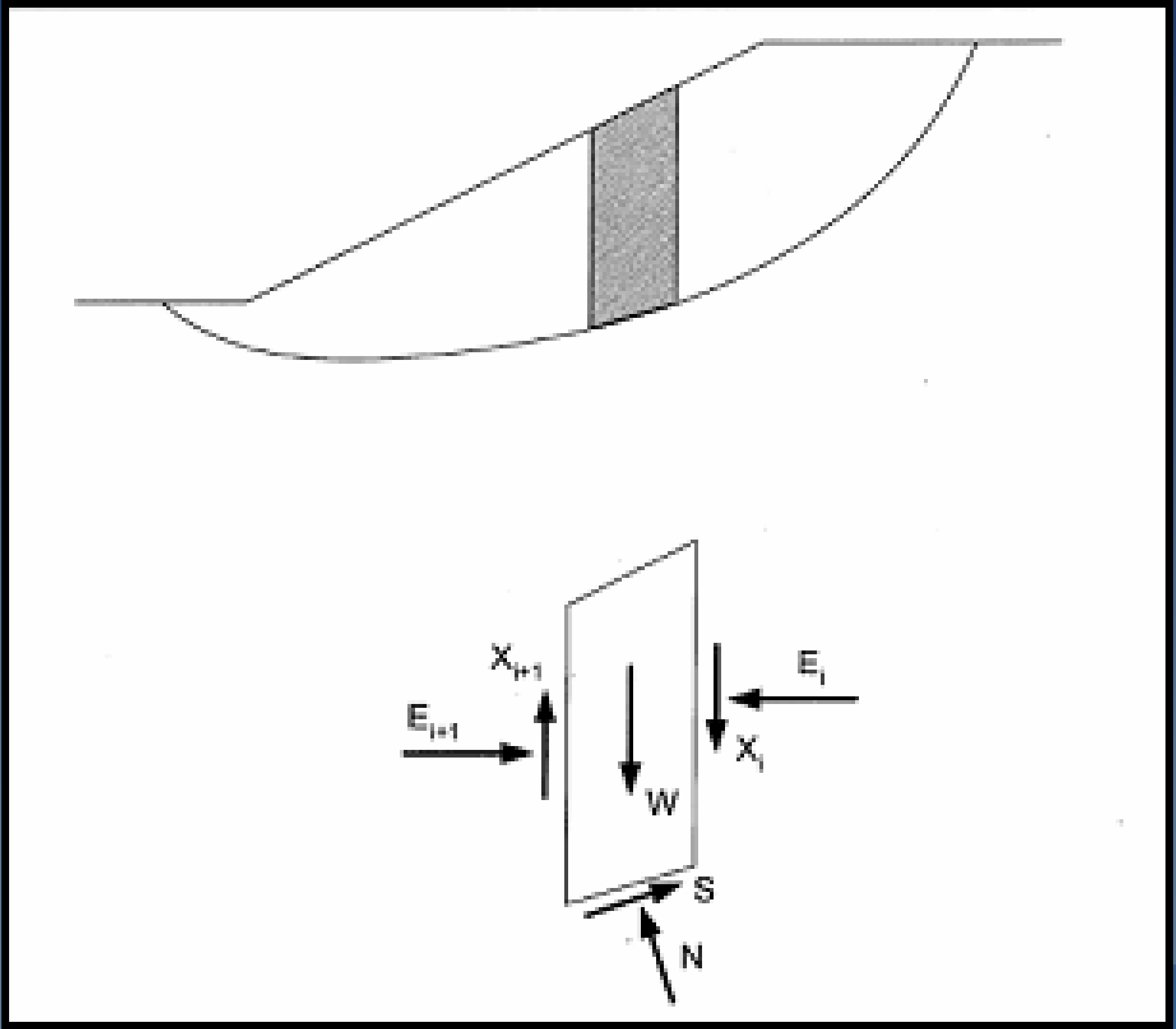
- Strength of Granular Materials comes from interlocking and frictional resistance between particles.

- Granular materials will have a relatively high value of ϕ.

Cohesive Material

- Strength of Cohesive Materials comes from electrical attraction between microscopic particles.
- Cohesive soils will have a high value of C.

Typical Slice and Forces for Method of Slices

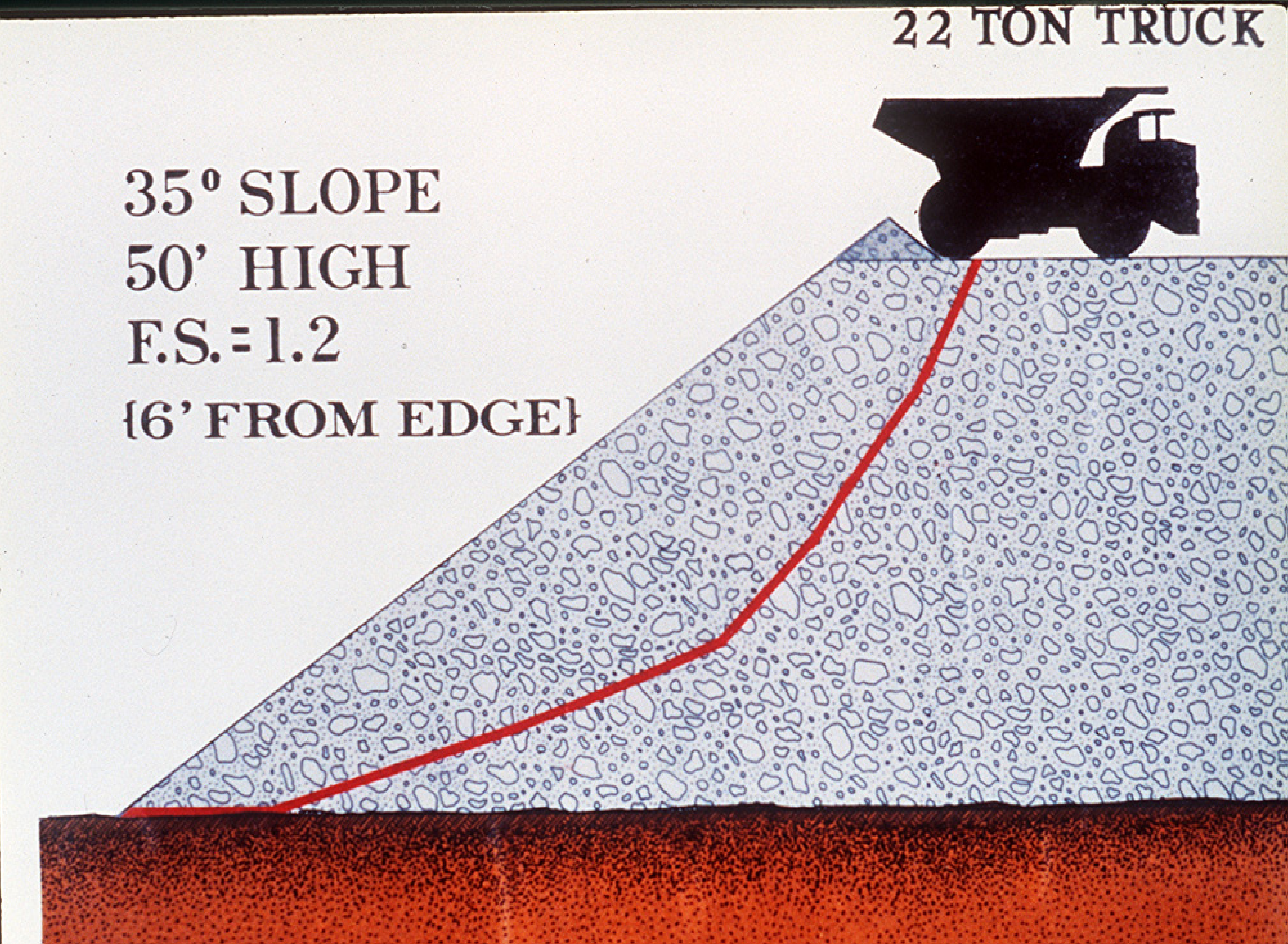


USACE 03: Slope Stability, Engineer Manual 1110-2-1902, USACE, 2003.

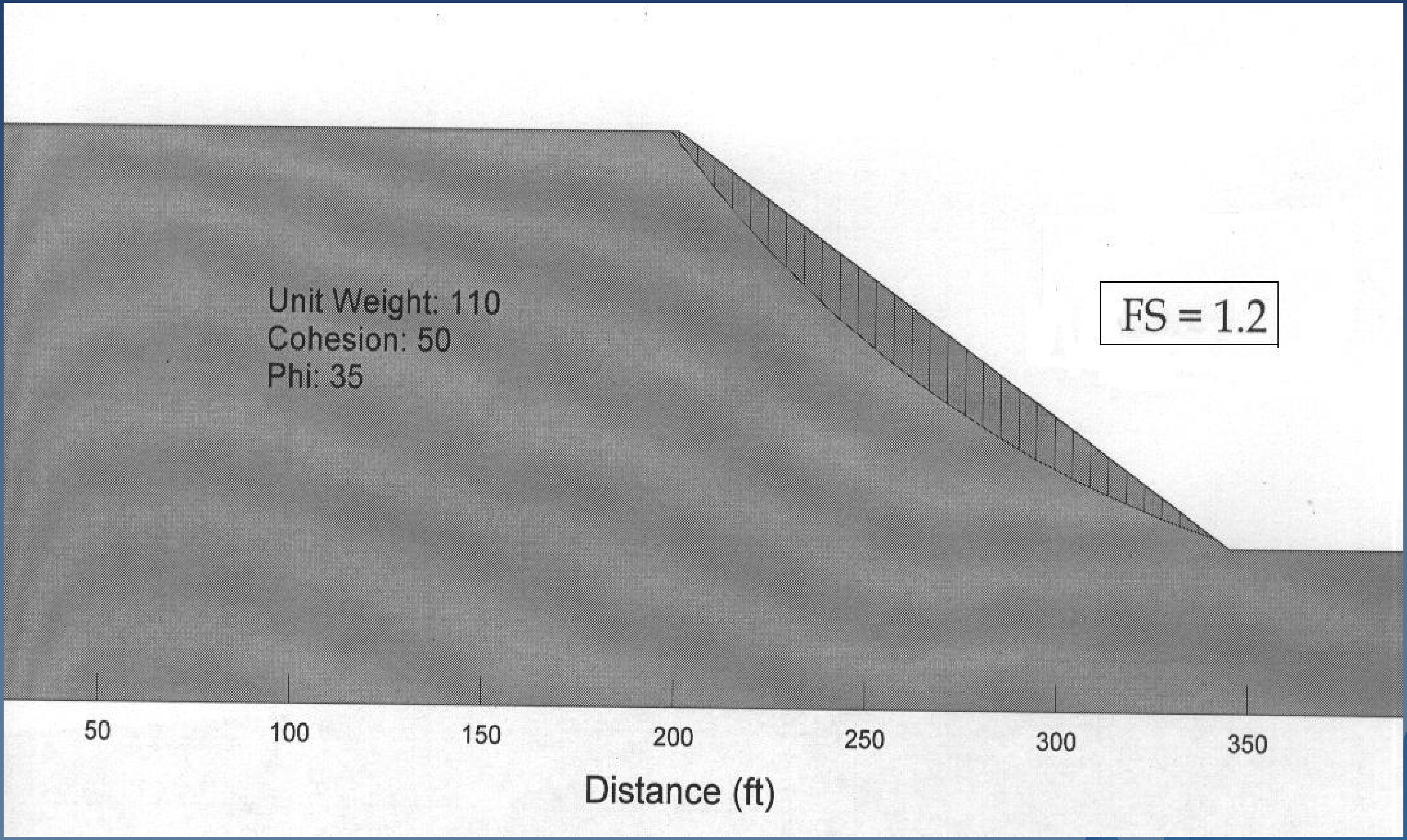
Factors which can cause a stable slope to become unstable

- Changes in Resisting Forces (Material Strength)
  - Weathering of rock
  - Lubrication by water
  - Internal water pressures
  - Loss of apparent cohesion by saturation or drying
  - Exceeding the strength of a weak layer
  - Sliding along weak layers

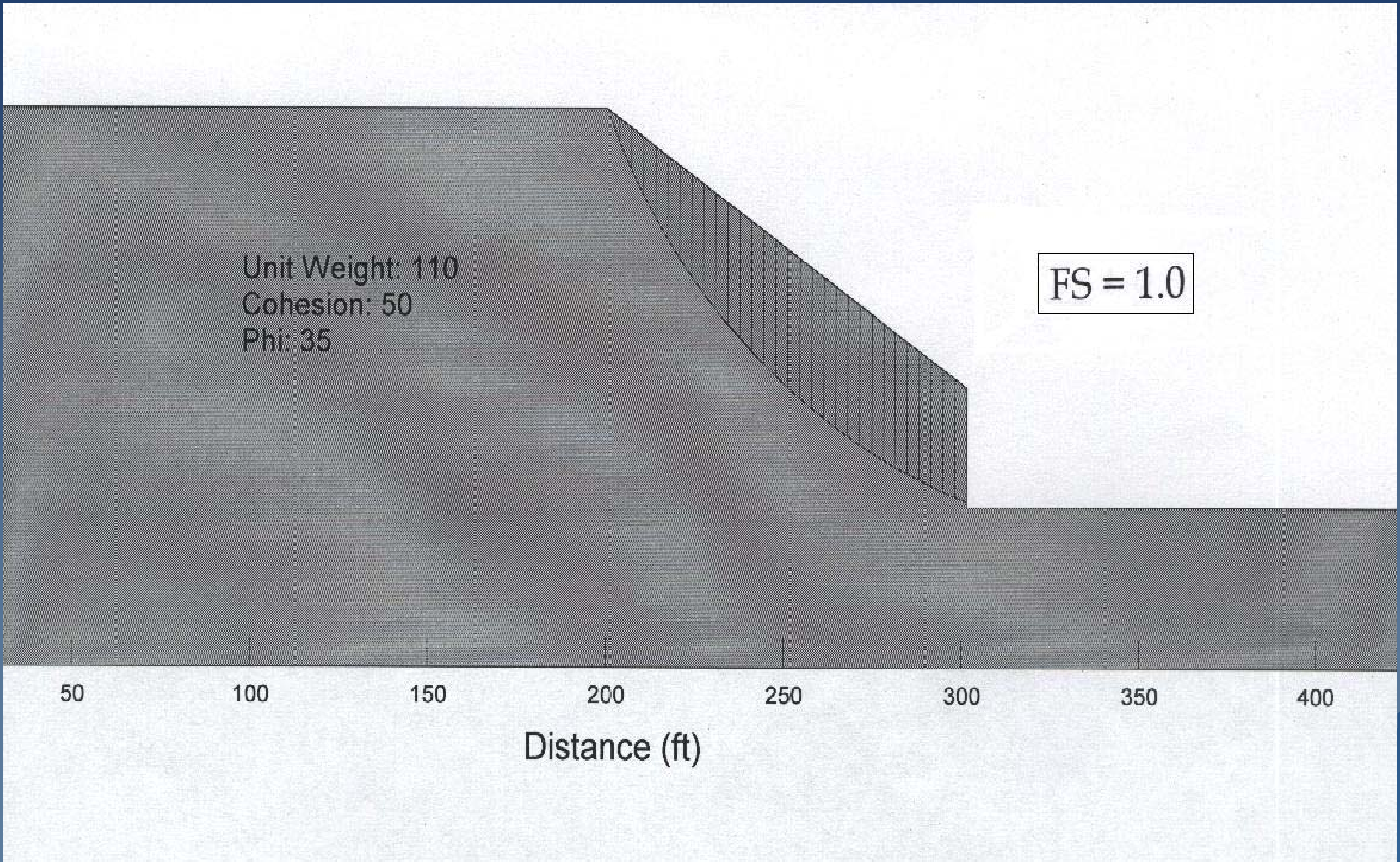
- Changes in Driving Forces
  - Adding Load to the top – truck, dozer, loader, or dragline
  - Outward force by truck braking near edge of a slope
  - Adding load to top by making the slope higher
  - Additional water weight (from precipitation or groundwater)
  - Removing support at bottom – trimming toe


22 TON TRUCK
35° SLOPE
50' HIGH
F.S.=1.2
{6' FROM EDGE}

Stable Slope FS = 1.2



Effect of Trimming Toe Material



Ground Control Plans are Unique

- Different Mining Techniques
- Different Geographic Conditions
- Different Geologic Conditions
- Different Mining Equipment

Open Cast Mining

Associated Stability Issues

Open Cast Mining – Area Method

Example 1
Strip Mine in Texas
30 OCT 2007

Massive spoil bank failure resulting from sliding along weak layer

Factors Contributing to Spoil Pile Failure

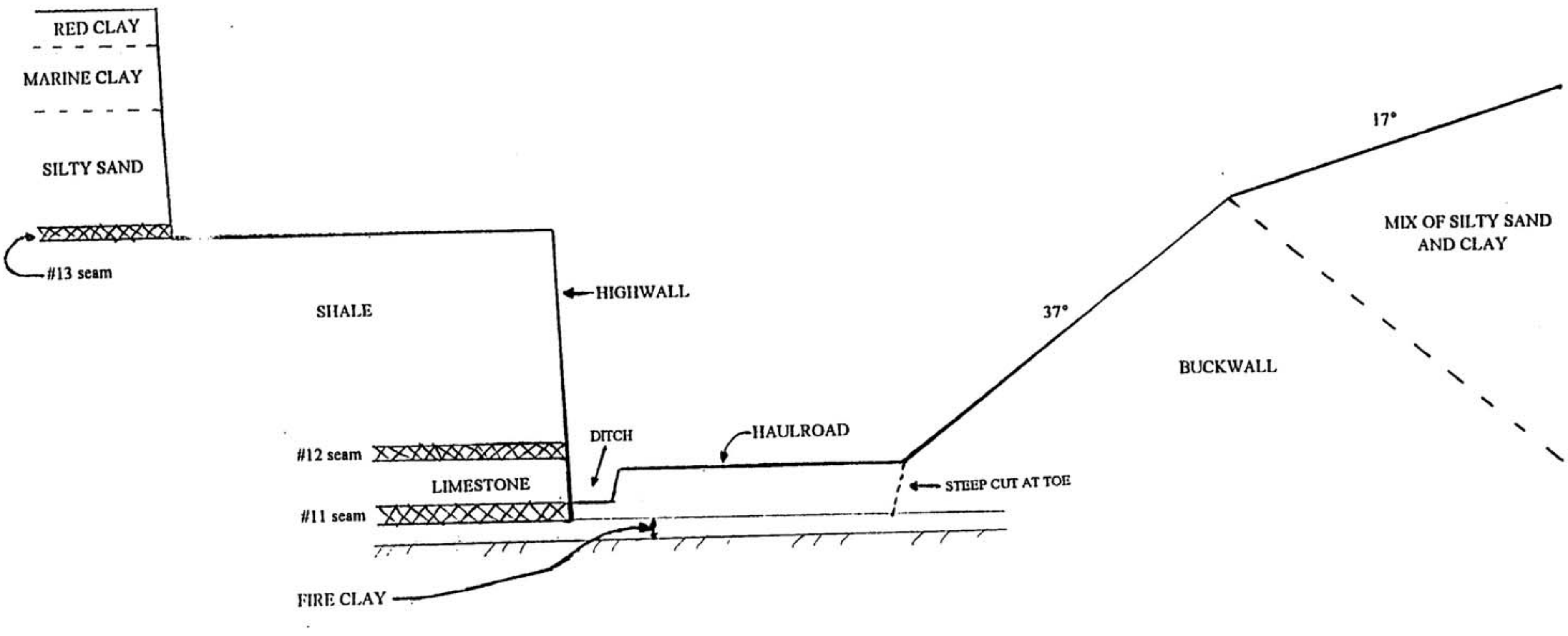
- Increase in depth of the coal seam resulting in more spoil and a higher spoil pile.
- Decrease in slope angle of highwall resulting in more spoil and higher spoil pile.
- Increase in groundwater seepage resulting in heavier spoil.
- Possible temporary increase in the slope angle due to <u>apparent cohesion</u>. The material loses the apparent cohesion as it dries out. (sand castle effect).
- Presence of gas well that could not be buried in spoil resulting in excess spoil piled adjacent to the gas well and higher spoil pile.

Example 2
Strip Mine in Western Kentucky
April 13, 2000

Massive Spoil Bank failure due to weak soil deposit incorporated in spoil

Mining Conditions

- 45 cu. yd. dragline used to remove 80 ft of overburden to expose 2 coal seams, creating a 100 ft wide pit
- Pit floor comprised of soft fireclay layer
- Mining through the flood plane of an old river channel, consisting of very soft wet stream deposits.
- In order to deal with these difficult conditions, the dragline was used to cast the shot rock (shale) on opposite side of pit to form a 80 ft high buckwall (angle of repose 37 deg.)
- clay material was placed immediately behind buckwall, followed by silty sands and other wet soil/mud material (angle of repose 17 deg.)



TYPICAL CROSS-SECTION

Spoil Slope Failure

- April 11, 2000, large mass of spoil slid into the active pit
- Failure was preceded by rocks rolling down into the pit; miners were evacuated; then the spoil mass failed within a half-hour later
- Company breached top of spoil buckwall to allow additional soft clay and sand to flow down into the pit.


4 14'00


Back-scarp
4 13 '00


4 13'00

Description of Slide

- Massive translational and rotational slide
- The spoil mass slid along the fireclay material at the base of the spoil bank, and there was also a deep-seated rotational slide within the spoil itself
- Top of slide mass was about 50 ft above the top of the buckwall, and left a 15- to 35-foot-high back-scarp
- Lateral extent of slide was 600-700 feet
- Buckwall reposed to about 33.5 degrees
- January 2000: 10-15 ft of water accumulated in pit bottom after heavy rainfall and sat there for several months. This most likely softened the fireclay and led to the failure

Example 3
Strip Mine in Western Pennsylvania

Steep excavation at the base of a spoil bank in an extended bench situation – No Failure


95 foot spoil pile 45 to 55 degree angle
95 foot high wall 80 degree wall angle
95 Foot high spoil bank 60 to 75 degrees


Best visual look at height of spoil pile.
Loose material that falls into pit
Pit Floor
Edge of coal


Top half of 190 foot
spoil pile

Observations

- The company had a false sense of security because they hadn't yet had a failure. They were mistaking temporary stability for long-term stability.
- They had convinced themselves that the dragline was compacting the spoil material and allowing it to safely stand long-term at these steep angles.
- In reality, this dragline on a 55-foot diameter tub, exerts about 12 pounds per square inch of pressure on the ground. In comparison, a compactor can exert up to 100 psi. Just a few feet below the surface, the effect of this dragline was minimal.

Trimming Material from Toe

- If a spoil bank is inclined at the angle of repose, the Factor of Safety is 1.0 (Marginal Stability)
- If material is removed from the toe, the Factor of Safety goes below 1.0, which implies long-term instability.
- The bank may be temporarily stable, but it is impossible to predict when it will fail.
- The practice of trimming the toe should be strongly discouraged.
- Trimming the toe can only be considered if it can be justified by an analysis showing that the volume of material expected to slide would not impact the operator considering the equipment being used.

Benching of Spoil Banks

- Placing spoil so as to leave benches can improve the overall stability of a pile and provide some protection against small slides and rockfalls.

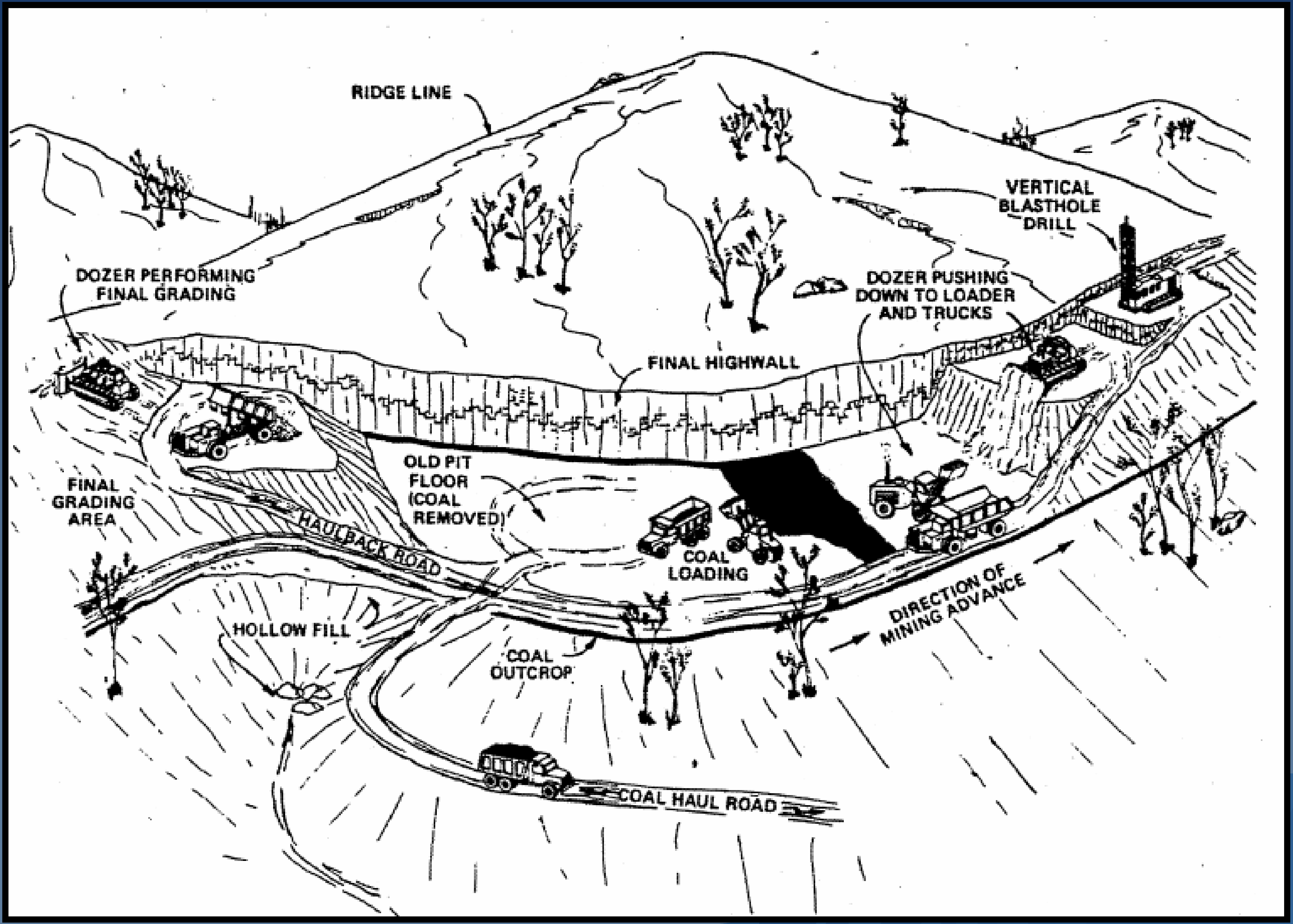
- <u>HOWEVER</u>, cutting benches into a spoil bank that is at the angle of repose can reduce its stability and cause slope failure.

Contour Mining and Mountaintop Removal

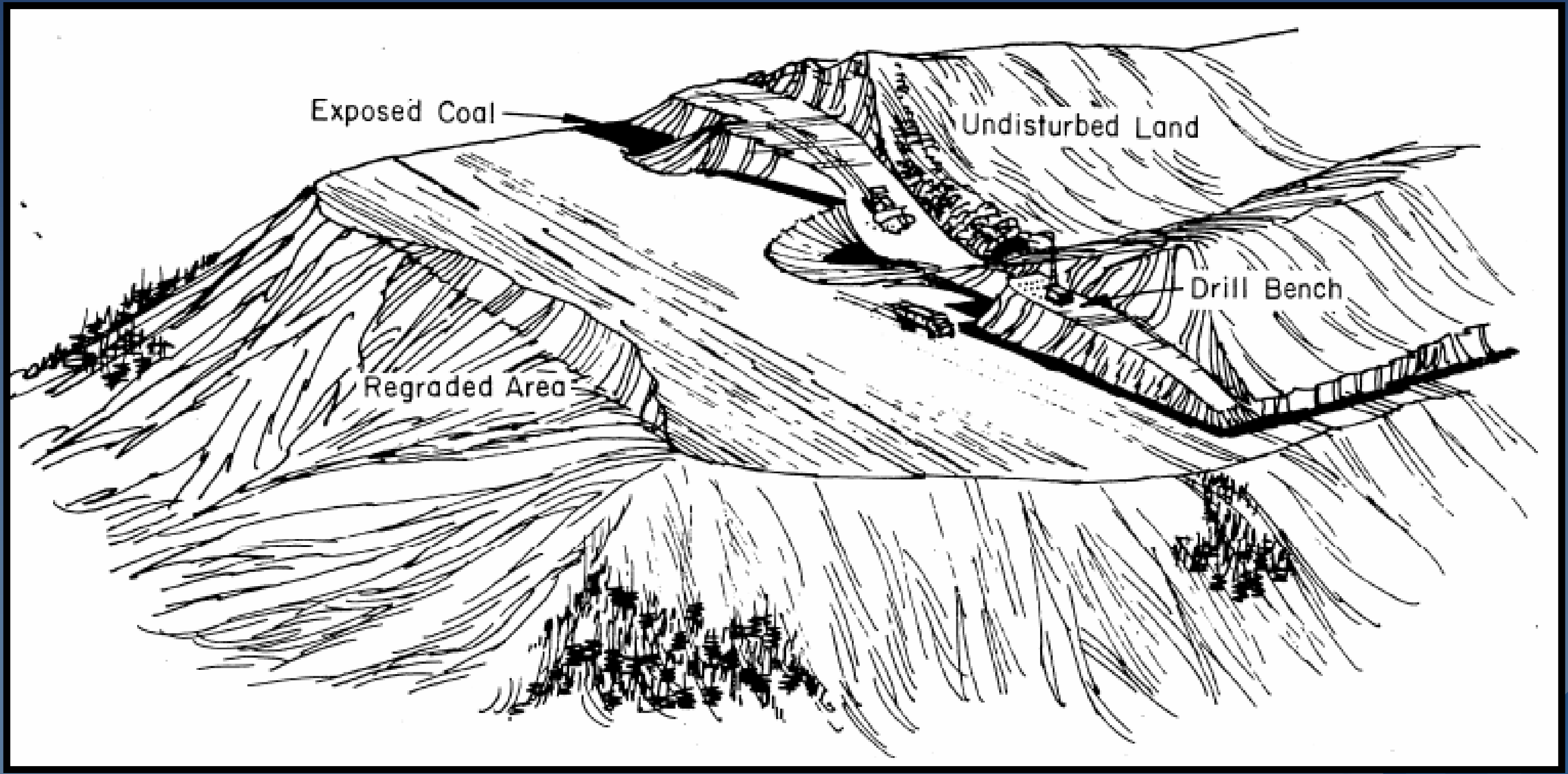
Associated Stability Issues

Primarily Dump-Point Stability Hazards

Contour Mining



Mountain Top Removal



Example 4
Mountaintop Mining in Southern West Virginia

Sliding along weak soil layer in the foundation of the spoil bank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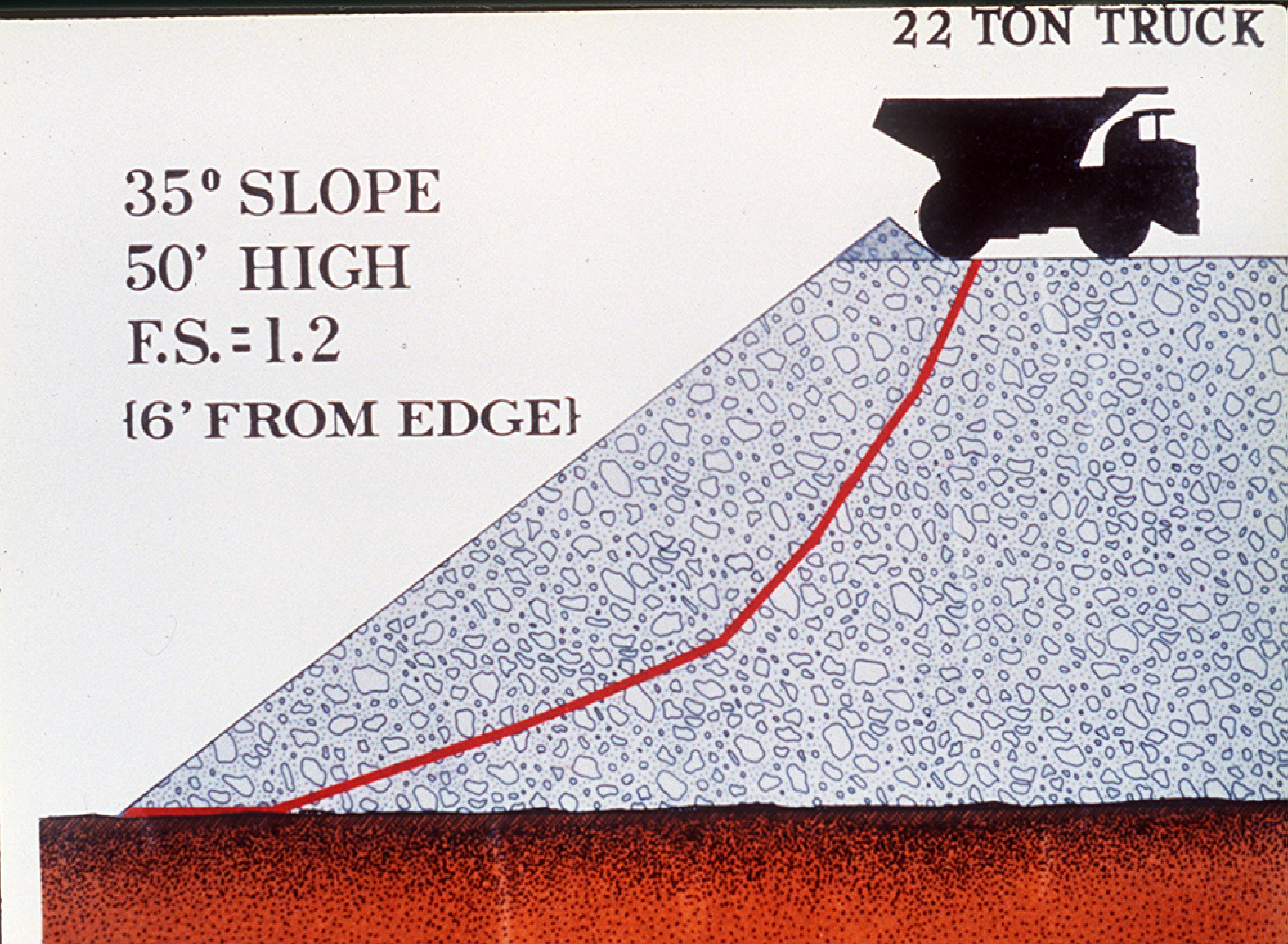
Example 5
Mountaintop Mining in Southern West Virginia
May 23, 2007

Sliding along weak soil layer in the foundation of the spoil bank and Trees / Vegetation in the toe area


22 TON TRUCK
35° SLOPE
50' HIGH
F.S.=1.2
{6' FROM EDGE}

Other causes of Dump Point Accidents

- Mechanical Failure
- Operator Error
- Backing at an angle
- Inadequate Berms

Purposes of Berms

- Provide a visual indication of the edge of the dump
- Provide a “feel” to the operator
- Provide some resistance to prevent overtravel
- Ensure that the truck is an acceptable distance from the edge of the dump

Summary - Conditions Discussed

- Truck dumps with natural weak soil
- Truck dumps with vegetation
- Dragline spoil with extended bench – excavated slope
- Trimming toe of spoil bank
- Variations of material – Impact on Stability
- Weathered spoil from past mining
- Alluvial Deposits
- Sliding along or beneath coal layer
- Inadequate Berms at Dump Points

INSPECTION, INSPECTION, INSPECTION

- "The best laid plans of mice and men oft go astray, and leave us not but grief and pain for promised joy."
- This is true of ground control plans. That is why inspection is the key, and plans are not cast in stone.
- Plans should be dynamic – they need to be modified when conditions dictate.

Inspection During Mining

- What to look for:
  - Cracks on top of the dump area
  - Cracks in the slope face
  - Vertical displacements
  - Bulging at toe
  - Rocks rolling from the bank
  - Concentrated seepage
  - Other unexpected conditions
- Inspect from a variety of vantage points when possible.

Cracks

- Not all cracks are a sign of impending slope failure. Cracks may also result from settlement of the spoil material, desiccation (drying out) of the ground surface, etc.
- Mine management should investigate the cause of any cracks. Factors such as the size, orientation, widening, and horizontal and vertical displacement of cracks provide clues as to their nature.

Take-Away Item #1

- Ground Control Plans should be unique to the mine – can not use a cookie-cutter approach. Plans should be developed with full consideration of:
  - Mining Methods
  - Site Geography
  - Site Geology
  - Available Equipment

(More on this in Ground Control Plan Presentation)

Take-Away #2

- No need for guess-work. There are well-established engineering techniques (e.g. slope stability and foundation stability analyses) available for evaluating existing and proposed ground conditions, and they should be used whenever warranted.

Take-Away #3

- Certain practices, such as excavating a spoil bank steeper than the angle of repose or cutting into the toe of a spoil bank are inherently dangerous and are not recommended.

Take-Away #4

- Direct truck dumping over the edge of a spoil bank has inherent hazards, and has resulted in many fatal accidents over the years, due to a variety of factors (e.g. operator Error, slope failure, inadequate berms, etc). There are precautions that can make the practice safer.

Take-Away #5

- Ground Control is not an exact science. But there are substantial engineering tools available.
- Inspection by the operator and by MSHA is critically important to ensuring safety.
- Ground Control Plans should be dynamic, and need to be modified if experience or conditions at a particular mine warrant.

For Additional Assistance

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