AIR & WASTE MANAGEMENT ASSOCIATION

Louisiana Section

Stability and Monitoring of Industrial Waste Landfills and Impoundments

by

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Landfill vs. Surface Impoundment (According to LA Regulations)

- Landfill: *"a facility for the disposal of solid waste, other than landfarm(s) or surface impoundment(s), that disposes of solid waste by placing it on or into the land surface and usually also compacting and covering with suitable cover material to a depth and at a frequency sufficient to control disease vectors and odors and in a manner that protects human health and the environment."*

Landfill vs. Surface Impoundment (According to LA Regulations)

- Surface Impoundment: "*facility consisting of a natural topographic depression, manmade excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials), designed to hold an accumulation of liquid waste and/or sludge, that is not an injection well, landfarm, landfill, or tank. Runoff and containment areas (ROCAs) of landfarms are considered to be surface impoundments*"

Landfill vs. Surface Impoundment (Simplified)

- Landfills – Store solid wastes
- Surface Impoundments – Store liquid wastes

Why Do Landfills Fail?

Landfills are man-made mountains

RUINED PYRAMID OF MEIDUM

(EVEN STONE MOUNTAINS CAN FAIL!)

Why Landfill Stability is Important?

Environmental, Safety, and Cost Concerns

- Threaten to human life
- Liners can be torn, maybe causing groundwater pollution
- Wastes can be released outside the boundaries
- Odor or other air quality problems
- Remediation/Reconstruction costs
- Property damage costs
- Reputation

Competing Slope Considerations

Flatter slopes = Less likely to fail = Engineers sleep better, but at the expense of their clients (Less airspace available)

Steeper slopes = More airspace, but more likely to fail

Example

100-Acre Landfill

Side Slopes 5(H):1(V)= 13 million cubic yards

Side Slopes 3(H):1(V)= 20 million cubic yards

Difference= 7 million cubic yards

$196,000,000 in savings!

Flatter vs Steeper Slopes

What slope should I use to construct my landfill?

- Site-Specific
- Slope Stability Analysis is the engineering tool used to balance the two competing slope considerations

Solid Waste Characterization

Solid Waste as a Geotechnical Unit

- Design and operation of waste landfills deal with the solution of geotechnical problems.

- <u>Application of geotechnical knowledge</u> $\Rightarrow$ some differences between solid wastes and soils properties (composition variability, changes of some properties with time, difficulties in obtaining representative samples)

Solid Waste Characterization

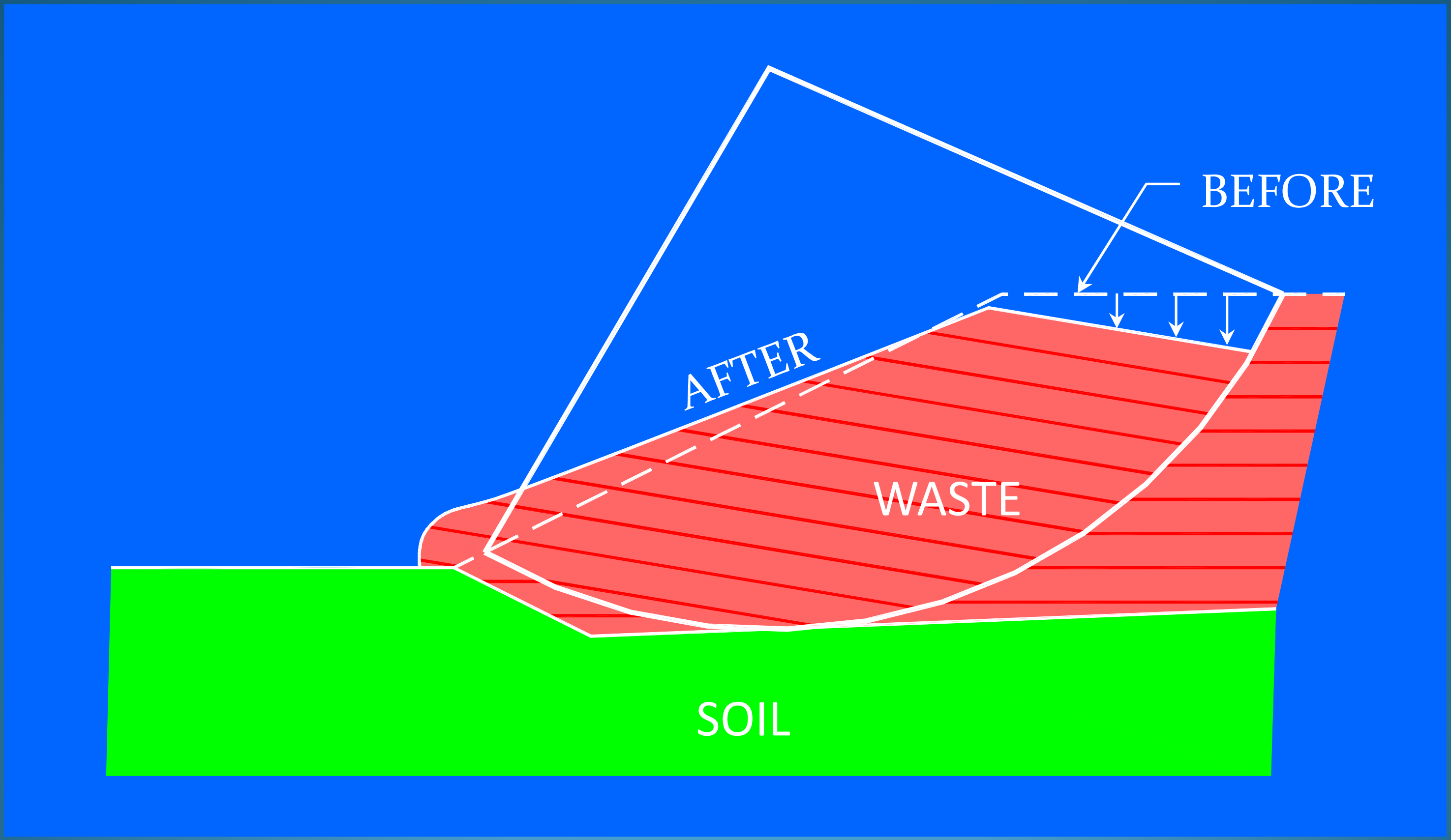
Not All Wastes are Equal

- Municipal Solid Wastes (MSW)
- Construction & Demolition Debris (C&D)
- Industrial Wastes
- Oil/Gas Exploration and Production Wastes (E&P)
- Gypsum
- Spent Bauxite (Red Mud)
- Sludges
- Ashes

Failure Modes

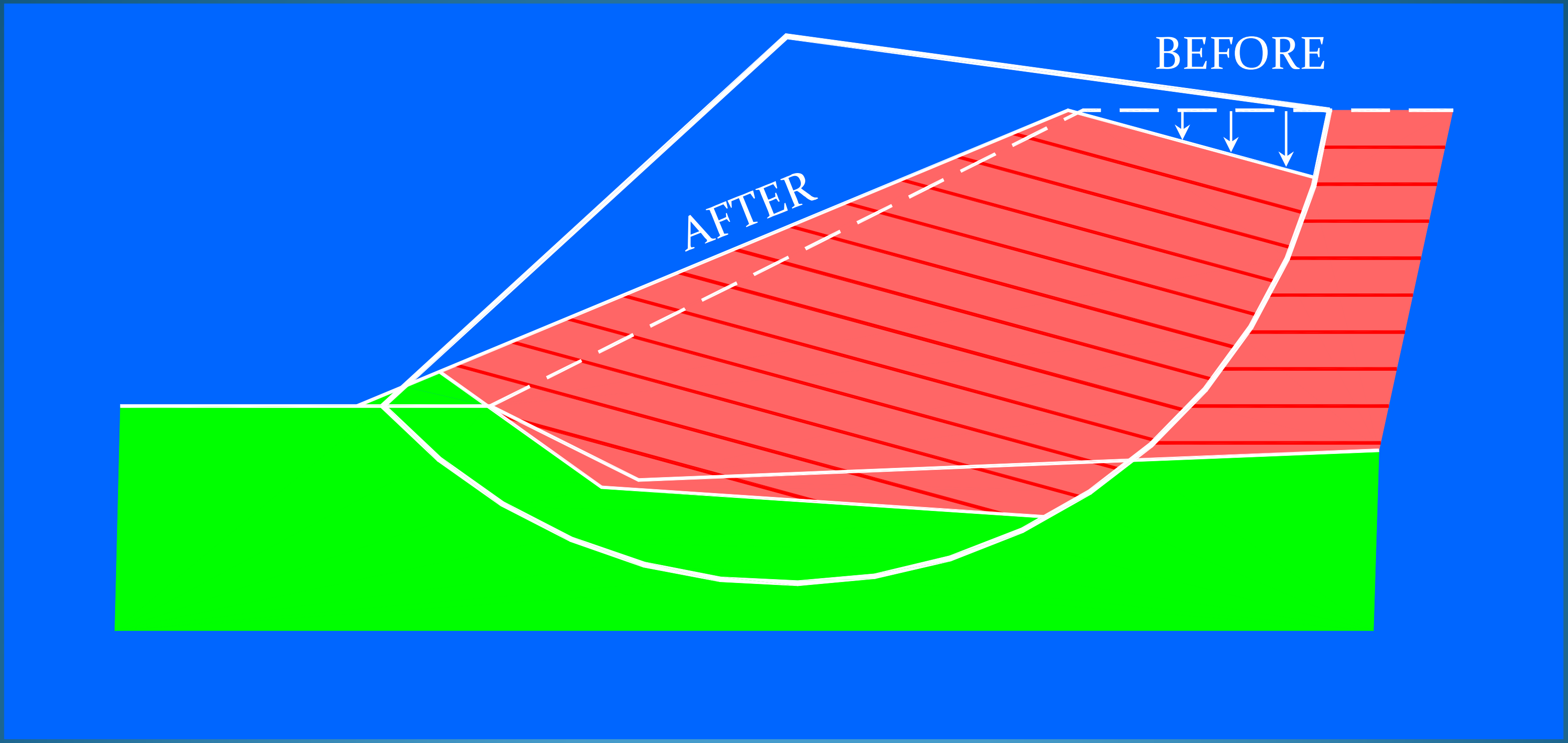
- Remember: Slides occur along the weakest surface
- In a 2-D Model analyzing the cross-section of a slope the weakest surface is represented by an arc of circle (if there is not a weaker plane).

Landfill Failure Modes



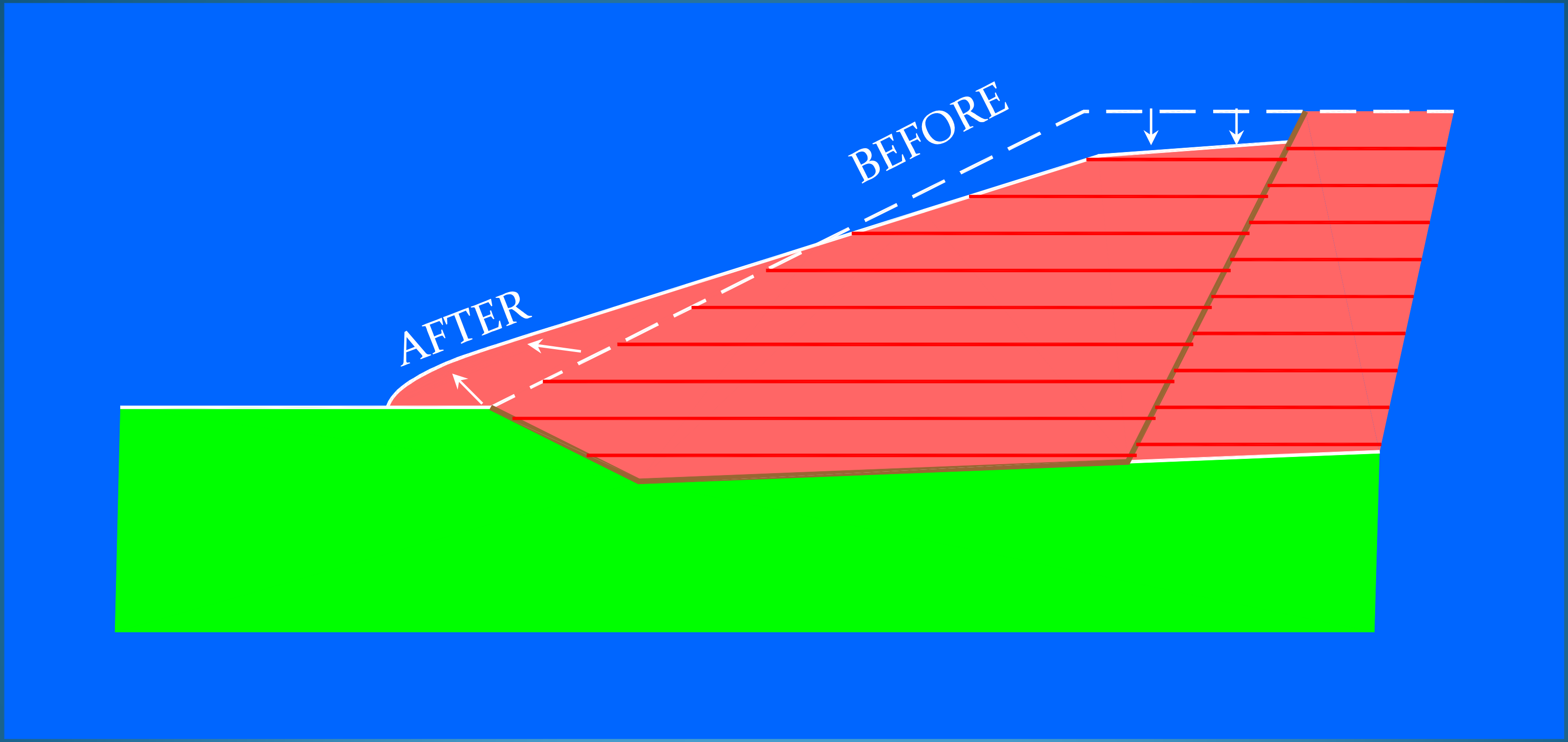
FAILURE IN WASTE MASS

Landfill Failure Modes



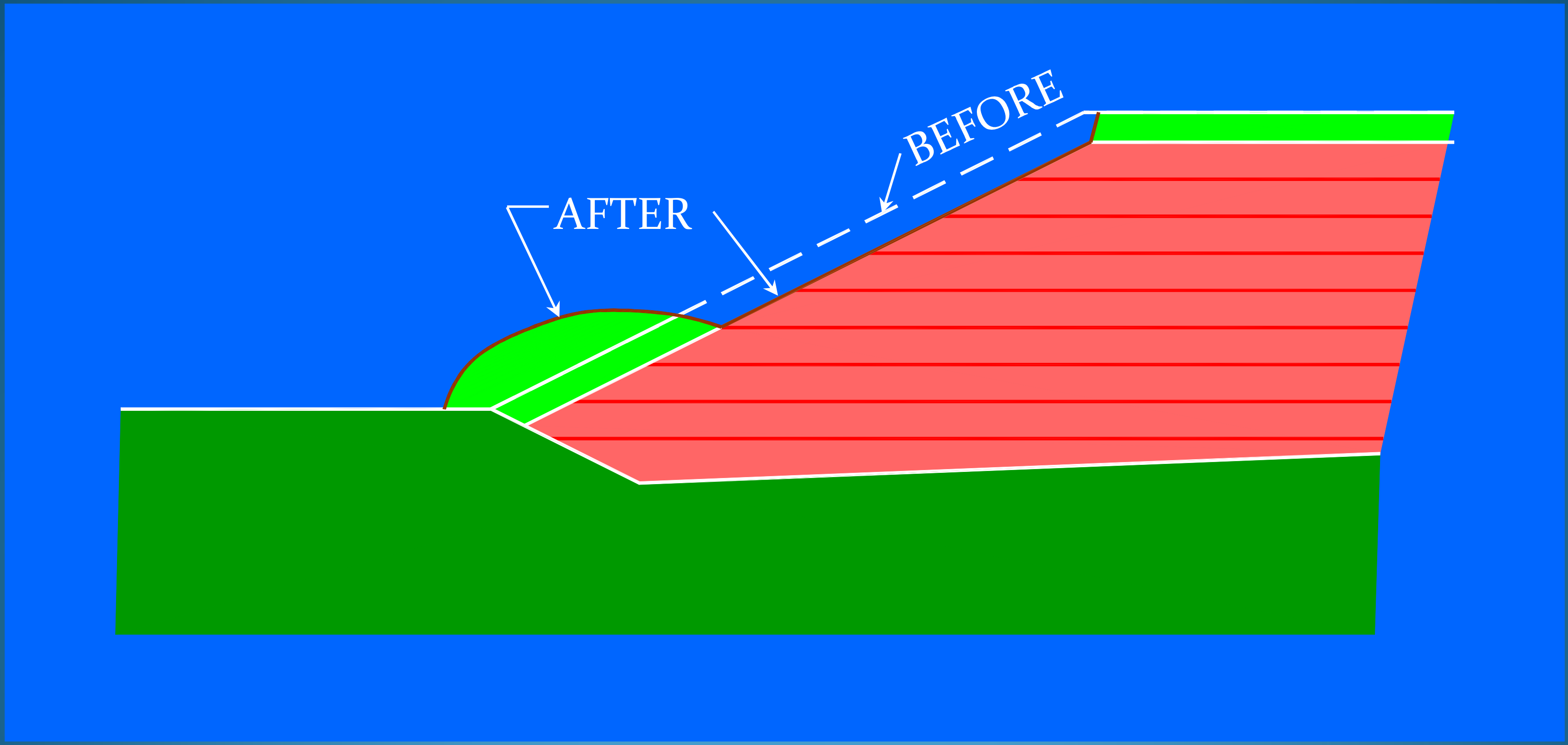
FOUNDATION FAILURE

Landfill Failure Modes



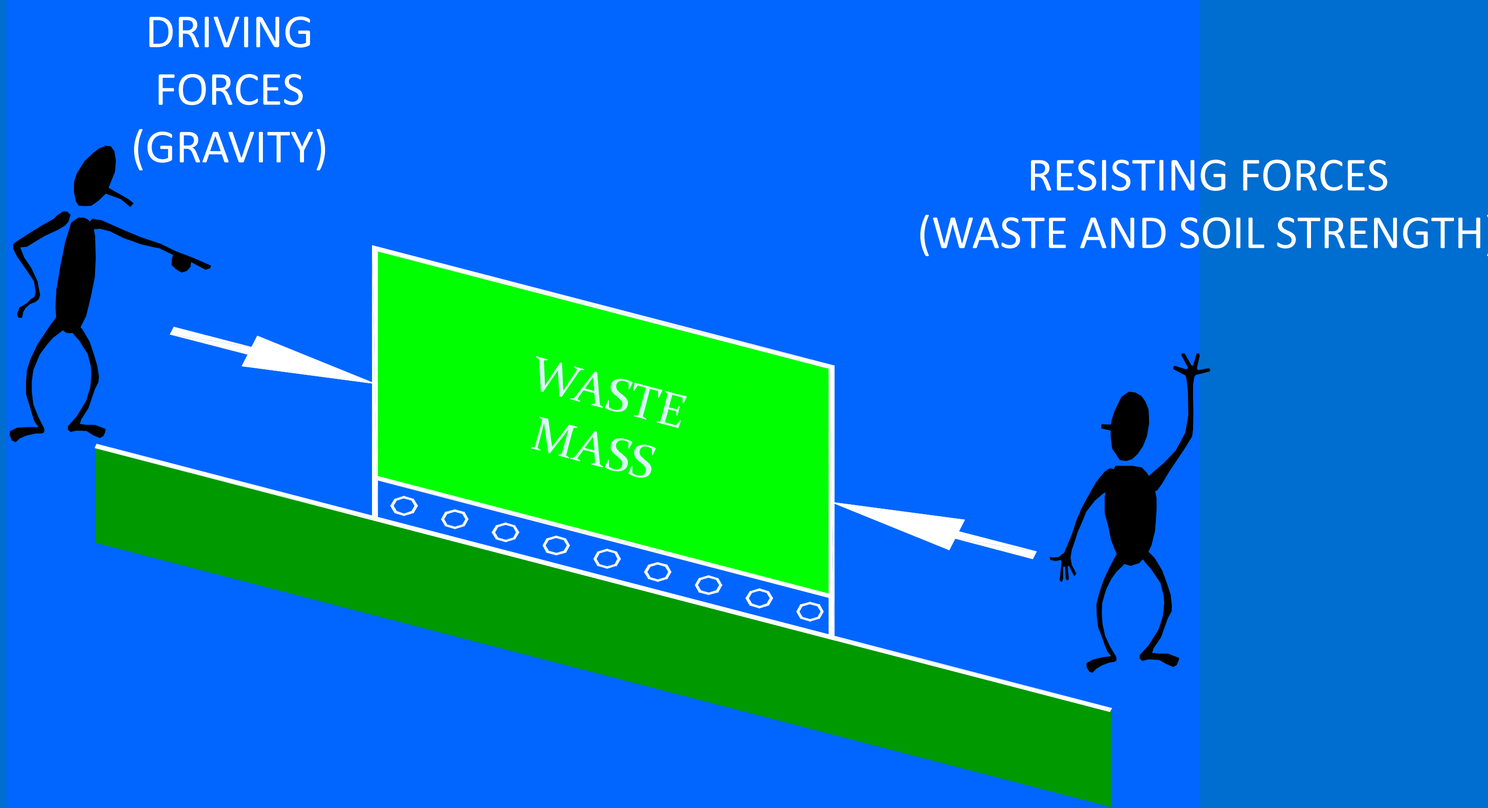
INTERFACE FAILURE

Landfill Failure Modes



SURFICIAL FAILURE (COVER FAILURE)

Generic Slope Stability Analysis



$$\text{SAFETY FACTOR} = \frac{\text{SUM OF RESISTING FORCES}}{\text{SUM OF DRIVING FORCES}}$$

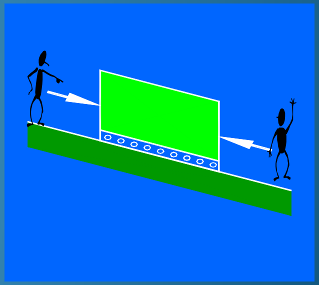
$SF = SF_R / SF_d$

Slope Stability Safety Factors

$$SF = SF_R / SF_d$$

SF	COMMON MEANING
>2.0	Extremely stable slope
1.5	Typical requirement for potentially life-threatening situations [1]
1.3	Commonly accepted as stable
1	Incipient Failure
<1	Failure

[1] OFTEN REQUIRED BY REGULATORY AUTHORITIES

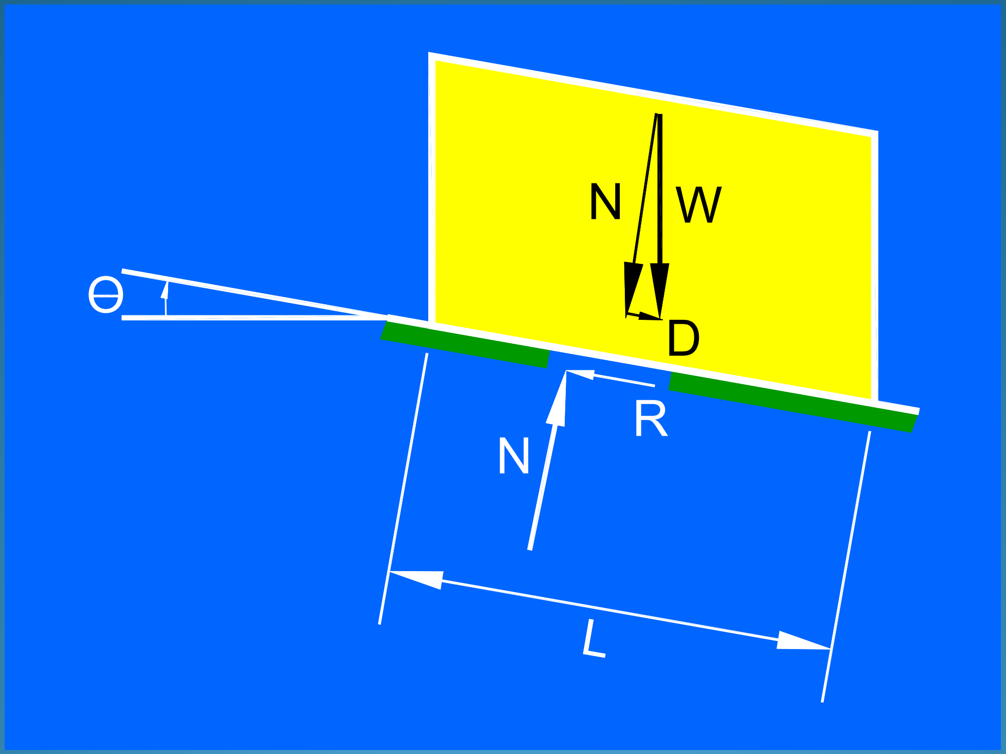


Slope Stability Safety Factors

LAC33:VII.711.B.7.c

"A minimum safety factor of 1.5 shall be required for all slope stability analyses unless an alternate safety factor is approved by the administrative authority".

Slope Stability Analysis



(FOR SECTION “A”)

DRIVING FORCE = D

RESISTING FORCE = R

D = W SINθ

R = CL + (WCOS θ) TANϕ

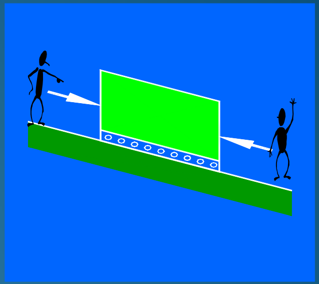
FORCES ON SECTION “A”

Slope Stability Analysis
Geotechnical Waste Properties

Cohesion: It “sticks together”, like dough.

Friction: The strength depends on how hard you push the material together, like when you rub two pieces of sandpaper together.

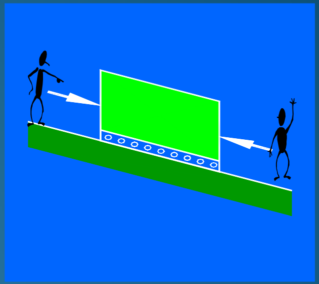
Slope Stability Analysis



Factors Affecting Driving Forces

- Unit weight of soil or waste (active weight – top of slope)
- Liquids inside the waste mass (hydrostatic forces)
- Slope angle

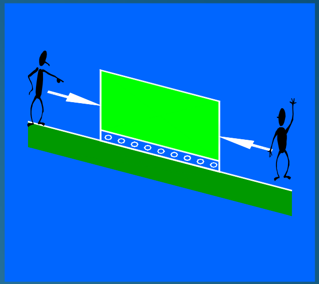
Slope Stability Analysis



Factors Affecting Resisting Forces

- Material type – shear strengths of waste and soil
- Passive weight – bottom of slope
- Liquids/gases inside the waste mass (pore-pressures)

Slope Stability Analysis



Basically, as “General Rule”:

- A steep slope is less stable than a flat slope
- A tall slope is less stable than a low slope
- Liquids/gases inside the waste mass can dominate stability

Different Wastes = Different Properties

Looking at Different Waste Properties and How They Affect Landfill Stability

Waste Characteristics

Boiler Ash

- Power plants produce mountains of ash.
- Fortunately, ash acts like a sand with a high friction angle (35^o-40^o). The material itself is therefore relatively stable.
- The foundation soil or synthetic interfaces usually govern stability.

Waste Characteristics

Gypsum

- Both the Louisiana-Texas area and the North Carolina to Florida area have many fertilizer plants.
- Most fertilizer plants have huge stacks of waste gypsum. Some gypsums are like sands or gravels: high friction angles. Others are like strong clays (high cohesions), but may be brittle.
- Stability is usually governed by the foundation soils. Stability usually requires controlled loading and is monitored by inclinometers.

Waste Characteristics

Red Mud

- It is a by-product of aluminum plants and typically behaves like a very weak clay. Stability is usually governed by the waste itself.
- However, if the red mud is dewatered prior to its placement, stability is greatly improved.

Waste Characteristics

Paper Mill Sludge

- The strength of this material can be almost anything. Slopes at 1(V):4(H) have been stable; failures have occurred at 1(V):10(H).
- If the sludge is dried before placement, it is fairly strong. If it is placed wet, it can flow like syrup. Stability is usually governed by the material itself.
- Paper mill sludges have fairly good friction angles (25^o-35^o), but low densities (45-65 pcf). If there is a water table in the sludge mass, the effective pressure (total pressure minus water pressure) will be low.

HOW TO ANALYZE SLOPE STABILITY WHEN YOU DON'T KNOW THE GEOTECHNICAL PARAMETERS OF WASTE?

Case Study: E&P Waste in Louisiana

Oil and Gas Exploration and Production Wastes (E&P Wastes)

- Wastes generated during the exploration, development, and production of crude oil, natural gas, and geothermal energy.

- Drilling wastes, salt water, and other wastes associated with the exploration, development, or production of crude oil or natural gas wells, considered non-hazardous.

Oil and Gas Exploration and Production Wastes (E&P Wastes)

Some examples:

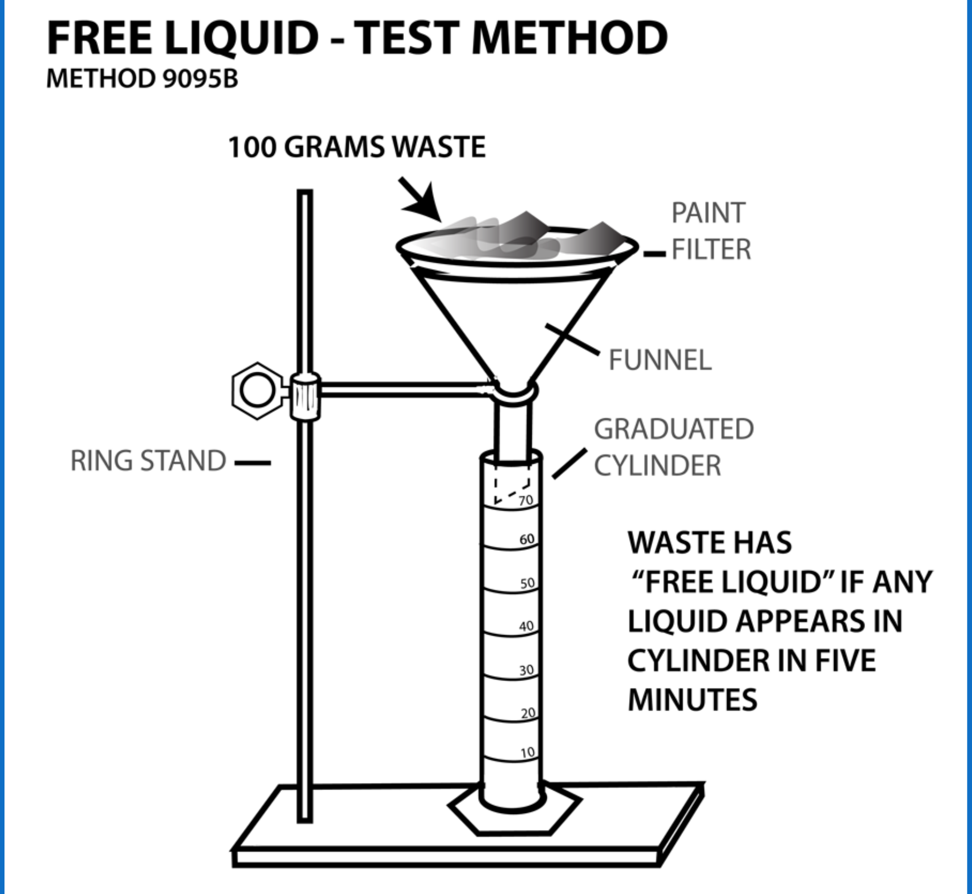
- Mud, fluids, and cuttings;
- Pit sludges;
- Storage tank sludges;
- Oily sands and solids;
- Washout water;
- Crude oil spill clean-up waste; and
- Other

Oil and Gas Exploration and Production Wastes (E&P Wastes)

- In Louisiana, certain types of E&P wastes can be disposed of at an industrial landfill. However, they may require solidification before final disposal.

- Waste is required to pass the paint filter liquid test tp be disposed of at a landfill.

Paint Filter Liquids Test



Source: www.epa.gov

The Problem

- To design new waste disposal cells at a landfill that would receive E&P wastes.

The Concern

- E&P wastes can have an impact on the slope stability of industrial landfills due to:
  - distinct shear strength
  - development of additional pore pressures due to the reduction of the hydraulic conductivities
- Literature about geotechnical properties of E&P wastes was virtually non-existent.

The Solution

- Design an expedited testing program to evaluate the geotechnical properties of the specific E&P waste to be disposed at the site.

The Testing Program

- Two phases (Phase I and Phase II)
- Classification tests
- Strength tests

Testing Program

- Particle size analysis
- Atterberg limits
- Field capacity
- Organic content
- Compaction
- Direct shear strength
- Hydraulic conductivity
- Triaxial compression (consolidated-undrained)

Testing Program
Sampling

E&P Waste

Solidification Agent
(Sawdust)

Testing Program Sampling

Results

Triaxial Tests

w = 200%

Analysis

Parameters – Slope Stability Analysis

- Sensitivity analysis
- Two sets of strength parameters:
  - c' = 14.4 kPa and F'= 23^o
  - c' = 23.9 kPa and F'= 27^o
- Pore pressure: r_u varying between 0 and 0.3

(Boscov et al., 2011)

Results

Slope Stability Analysis

Safety factors between 1.3 to 1.4 when set of very conservative parameters were utilized.

E&P Case Study Conclusions

- E&P waste has very distinct characteristics when compared to typical U.S. MSW/Industrial wastes (e.g., low hydraulic conductivity).
- Analysis of geotechnical characteristics of E&P waste <u>must be waste and site specific</u>.
- Adoption of a rigorous geotechnical monitoring program is recommended by the authors.

LANDFILL SLIDE CASE

Landfills have failed!

Landfill Slide Case

<u>Bandeirantes Landfill (Sao Paulo, Brazil)</u>

- June 1991
- Waste Acceptance Rate= 6,000 tons/day
- Approximately 250 ft high
- 4(H):1(V) average slope
- Heavy rainfall event observed before failure
- Failure within the waste mass

Landfill Slide Case

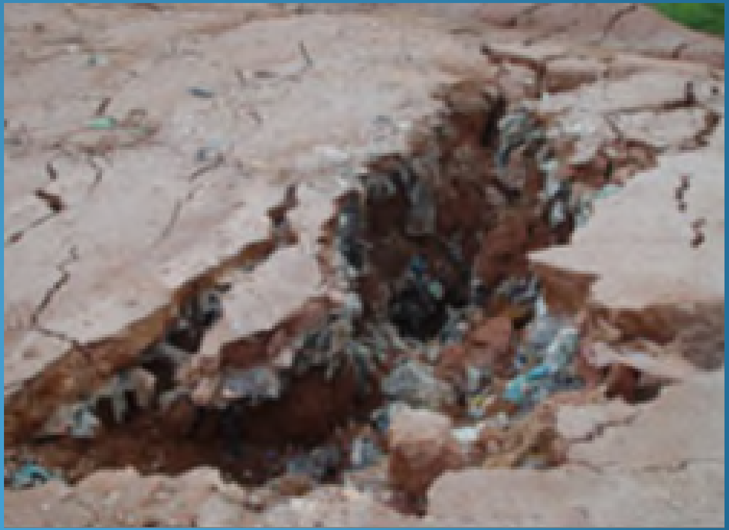
Bandeirantes Landfill (Sao Paulo, Brazil)

- Several cracks were observed on the top of the landfill before failure
- Failure was due to heavy rains, increase of liquids inside the waste mass, and a deficient leachate collection system
- After failure the regulatory agency required the geotechnical monitoring of the entire landfill!

Geotechnical Monitoring of Landfills

Just look!



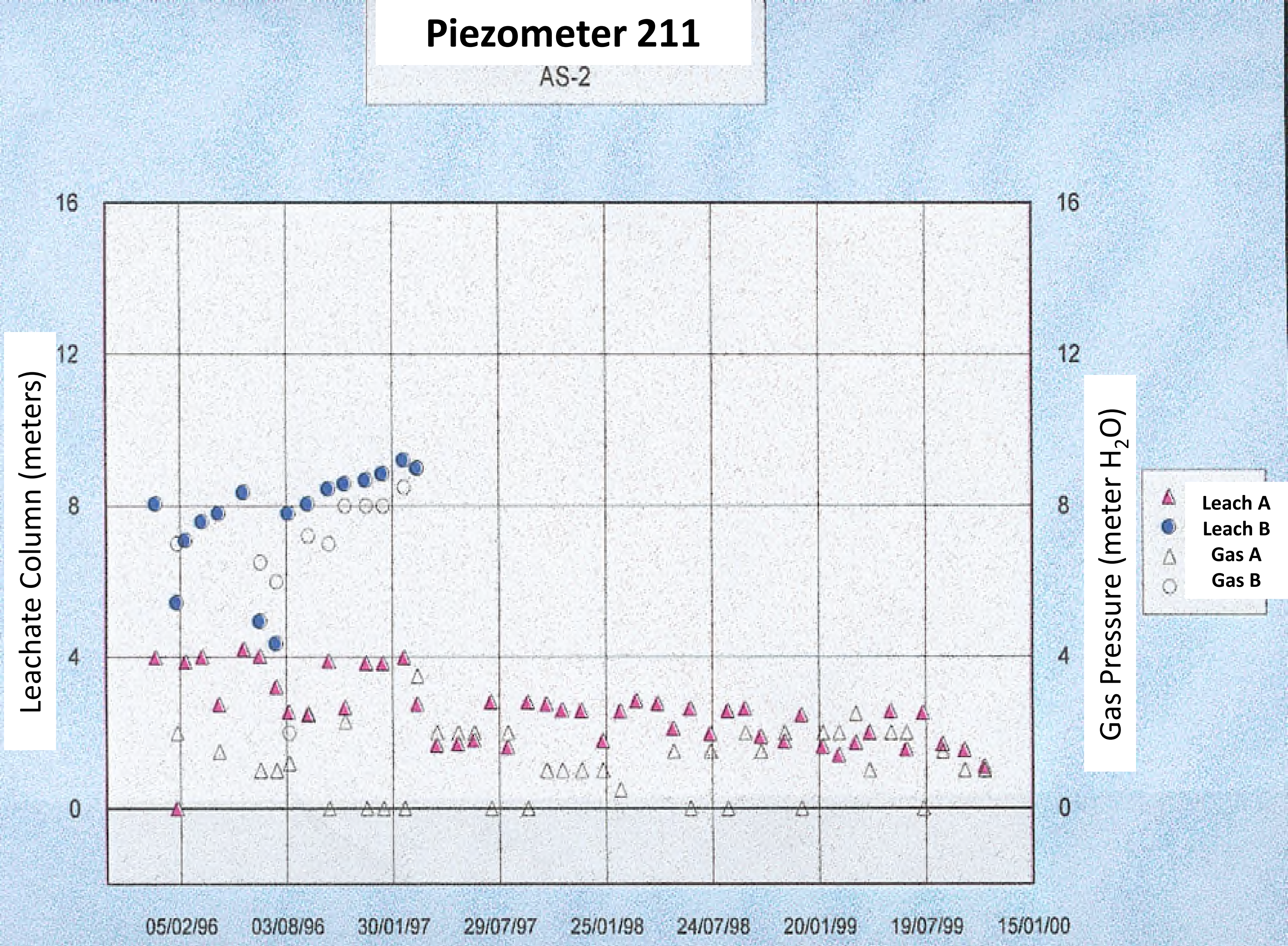



Other Components of Geotechnical Monitoring of Landfills

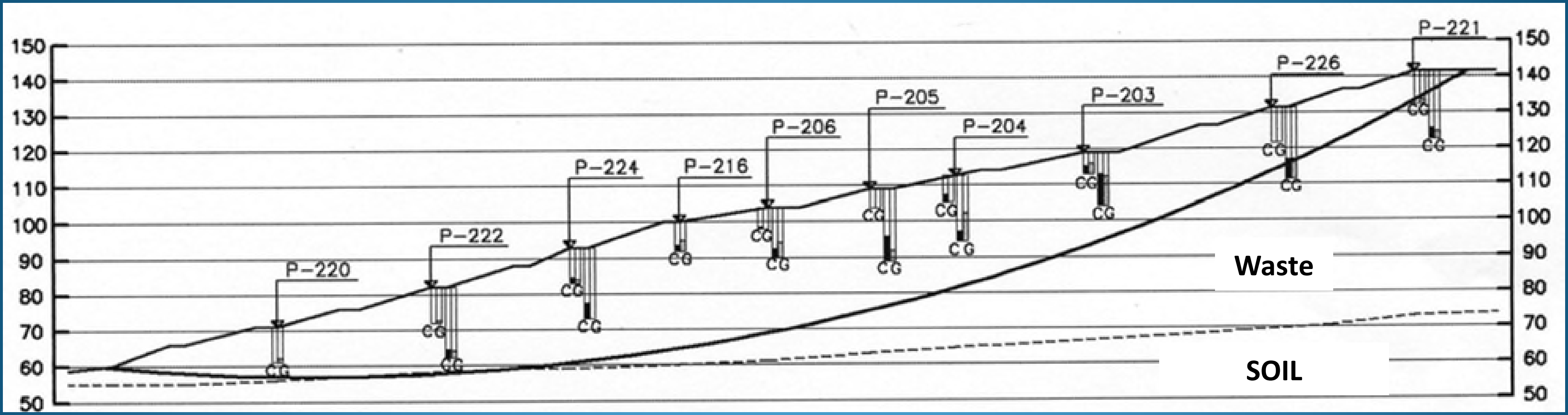
Double-chamber piezometers

Independent measurement of leachate and gas pressures

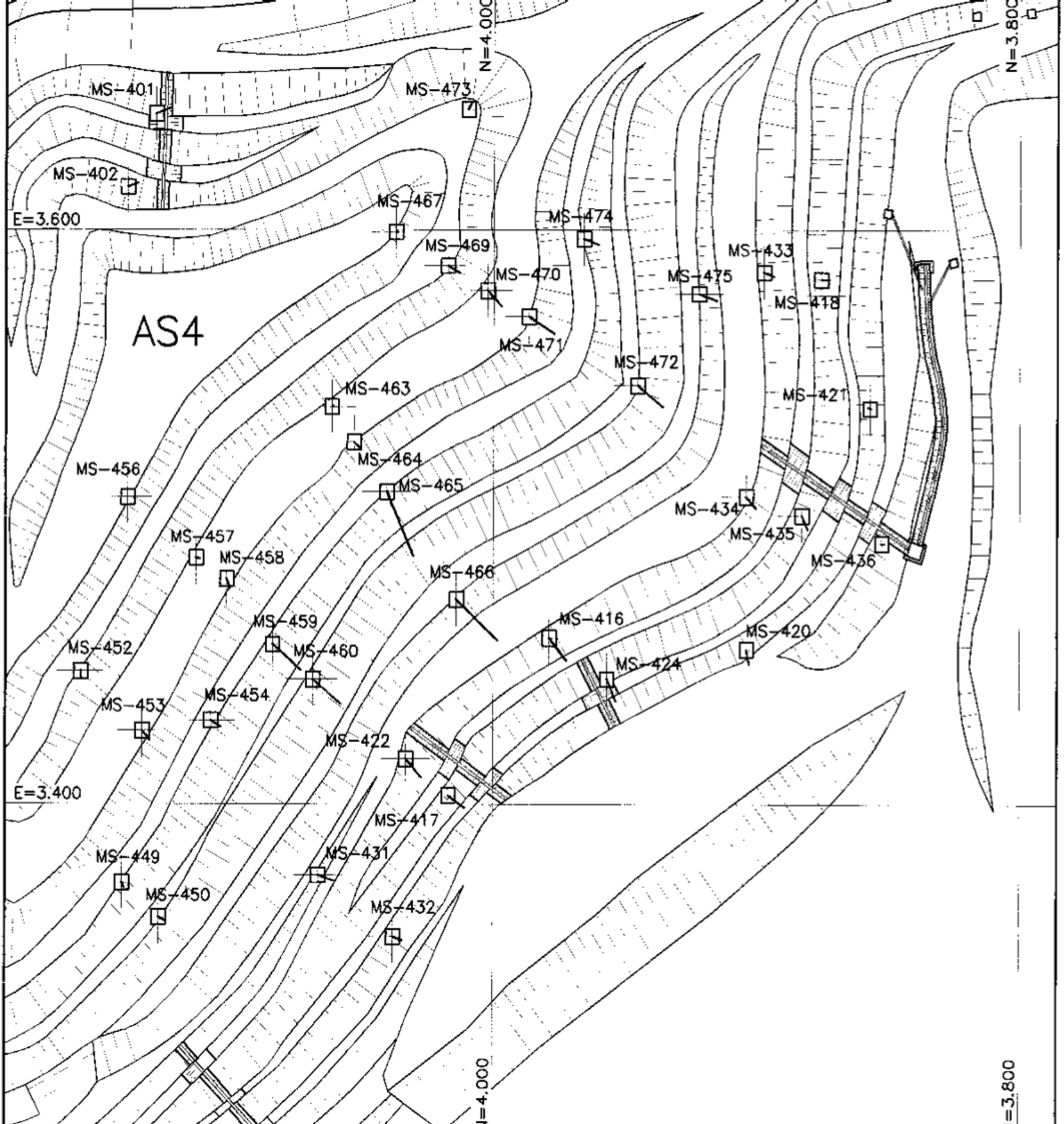
Piezometer 211



Slope Stability Analysis using piezometers




Surface Monuments
Vertical and Horizontal Displacement Monitoring



GEOTECHNICAL MONITORING

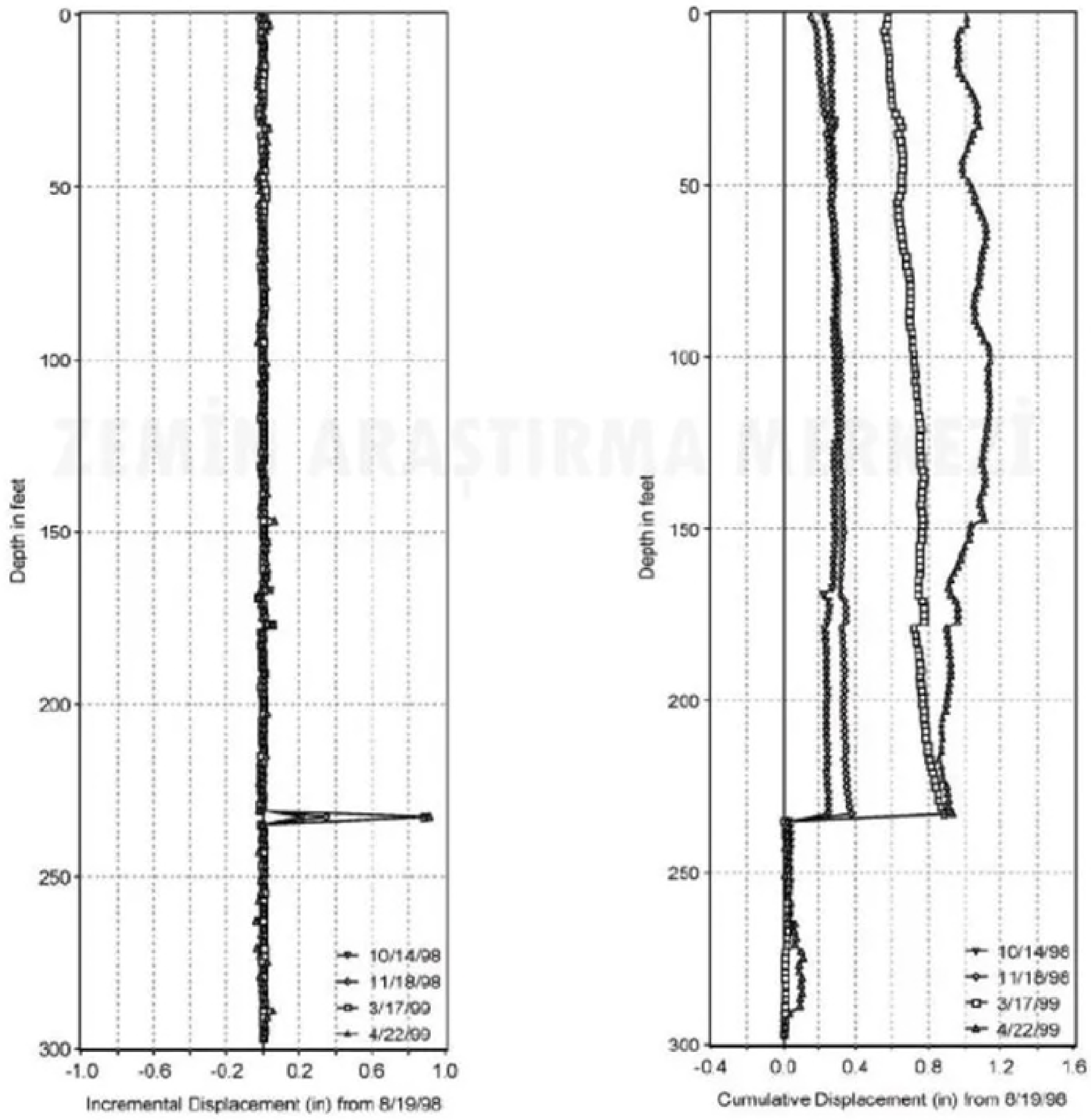
Graphical Scale Displacement Vector

0 5 10 15 **mm/day**

LEGEND:

Surface Monument and Horizontal Velocity Vector

INCLINOMETER

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