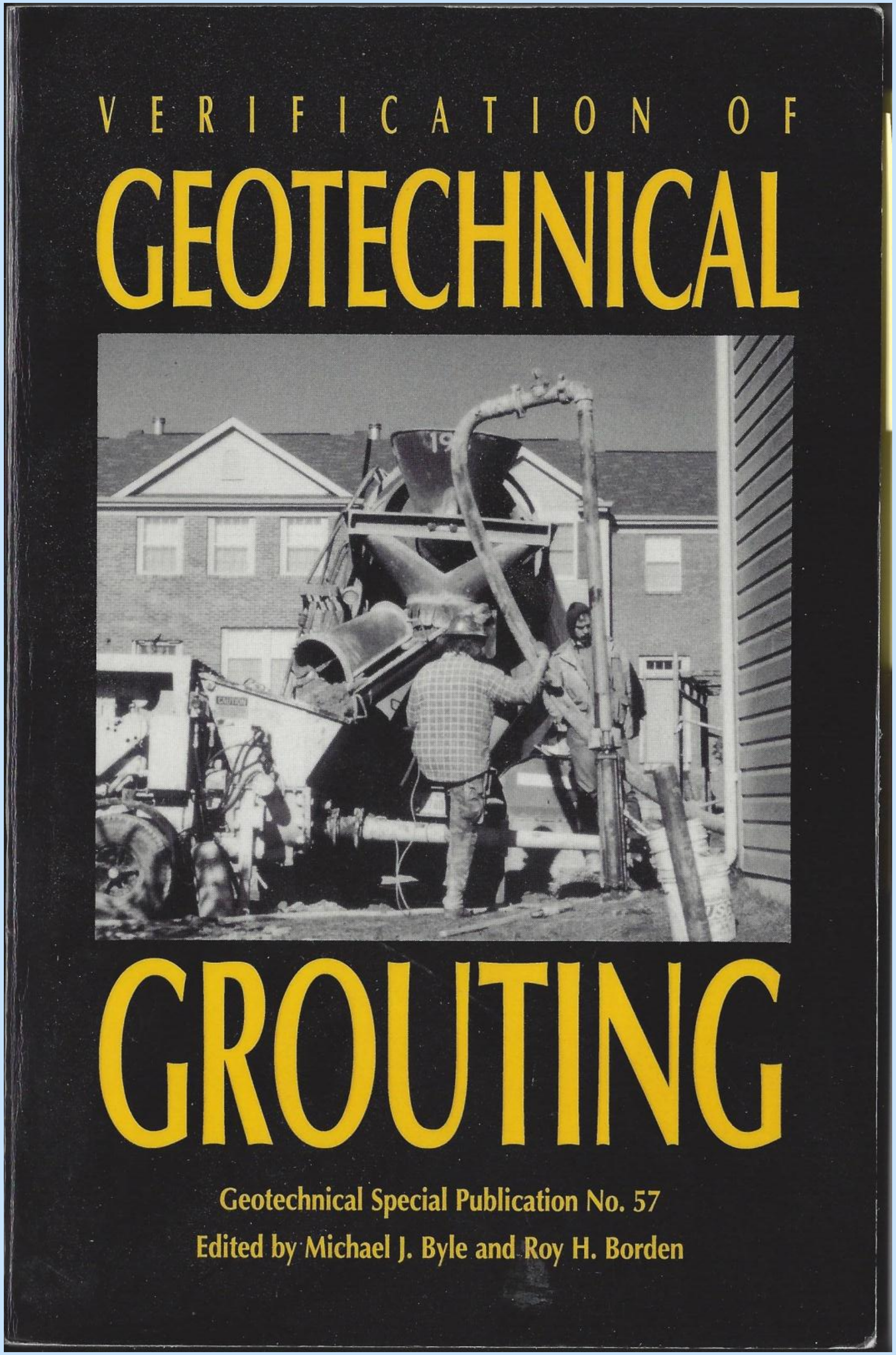
VERIFICATION OF GEOTECHNICAL GROUTING- STRATEGIES AND PLANNING

Michael J. Byle, D.GE, F. ASCE

TETRA TECH

Verification of Geotechnical Grouting was published By the ASCE Committee on Grouting in 1995

It is still available and still has useful information

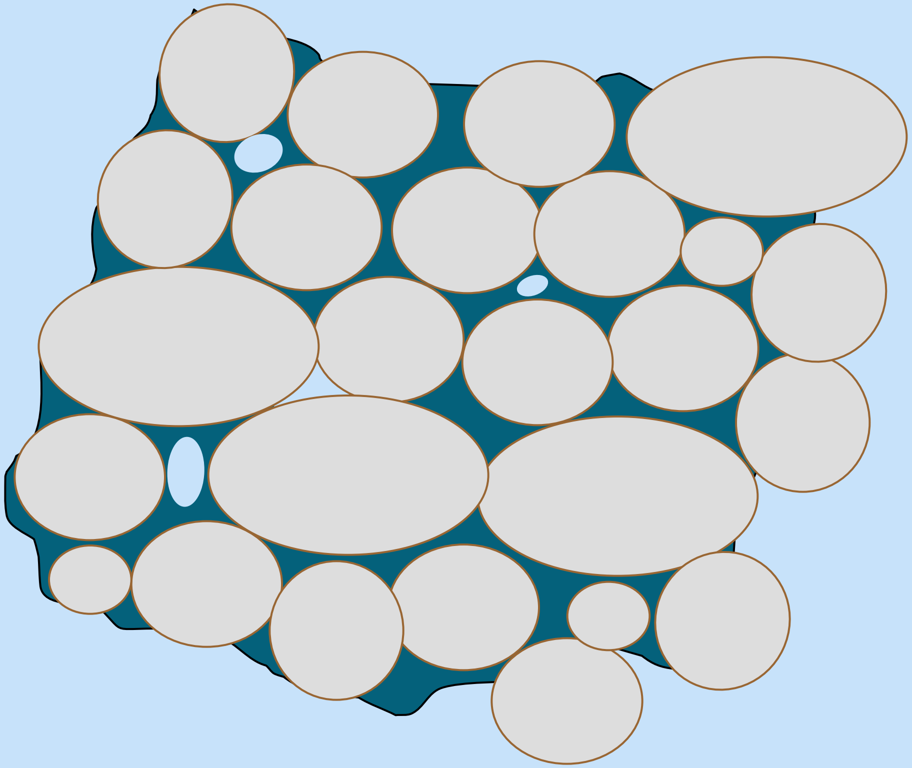


OUTLINE

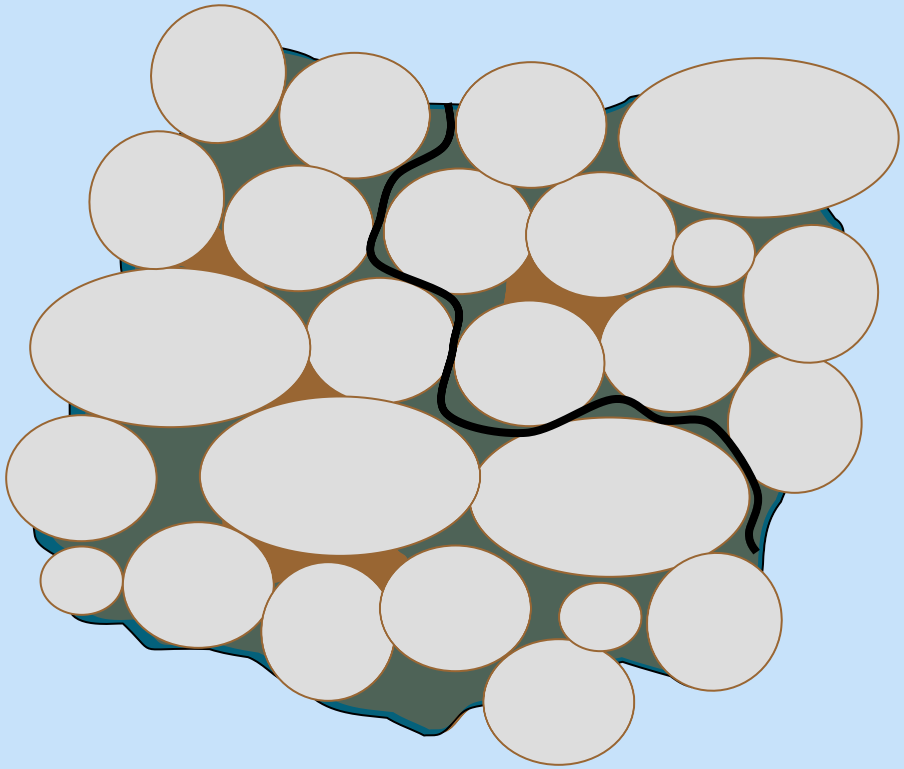
- Overview of grouting methods
- Identifying Basis for Verification
- Guidelines for planning verification
- Methods for verification
- Summary

Overview of Grouting Methods

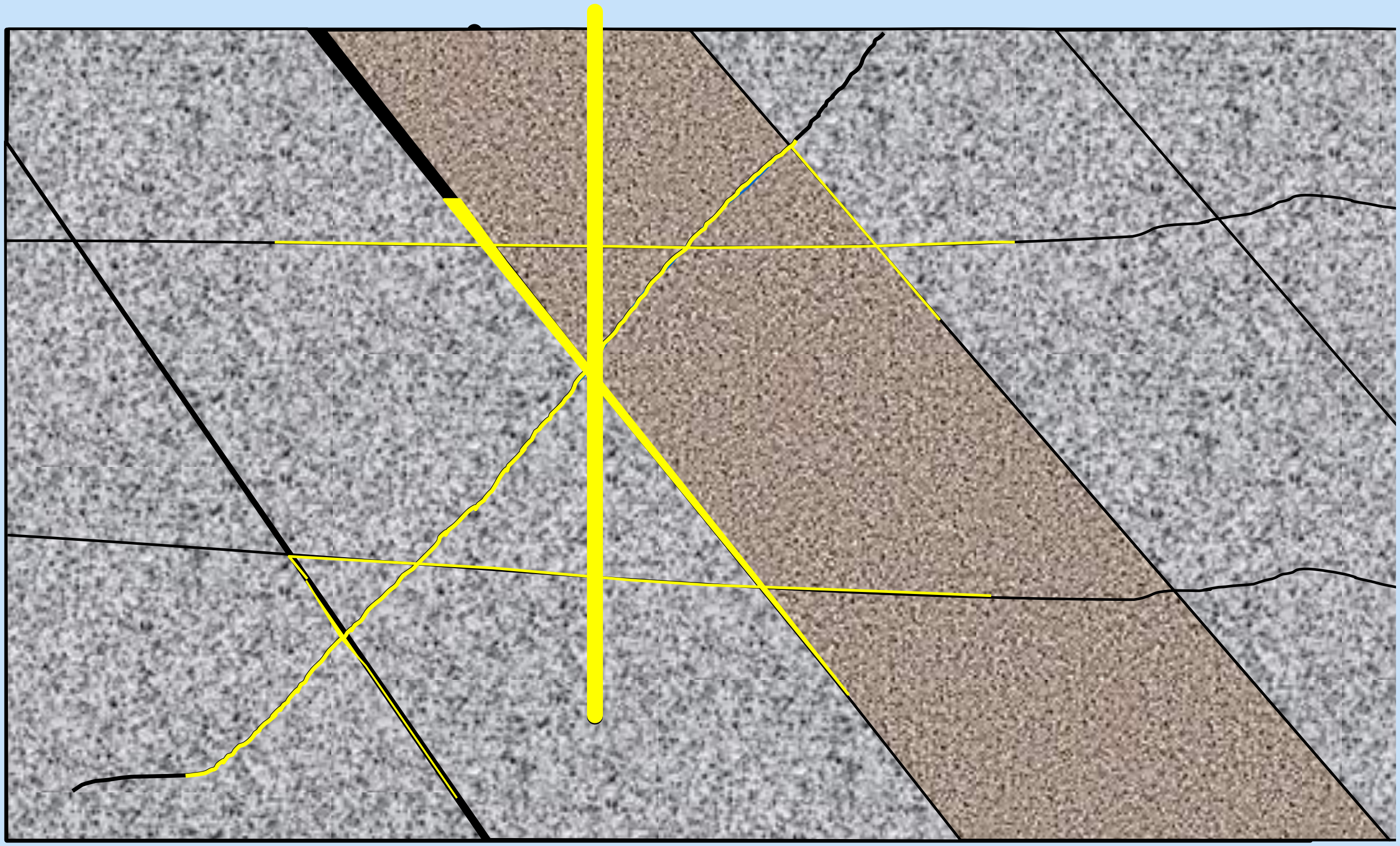
Permeation Grouting



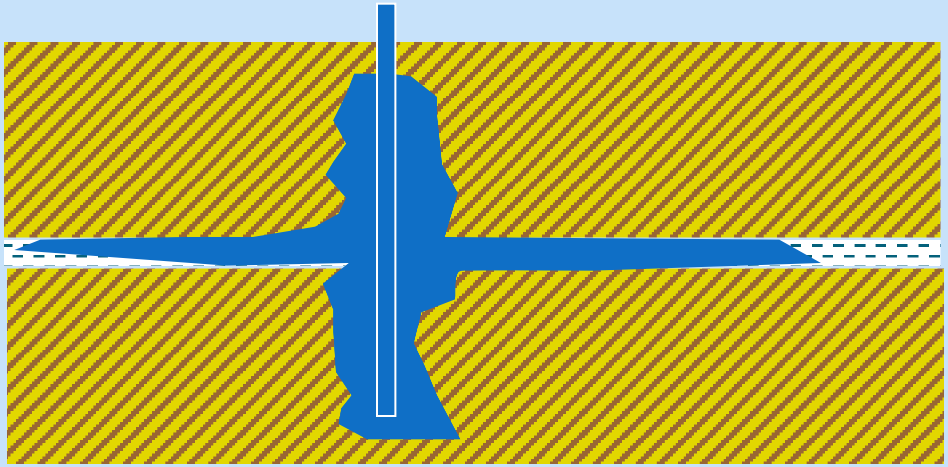
Permeation Grouting



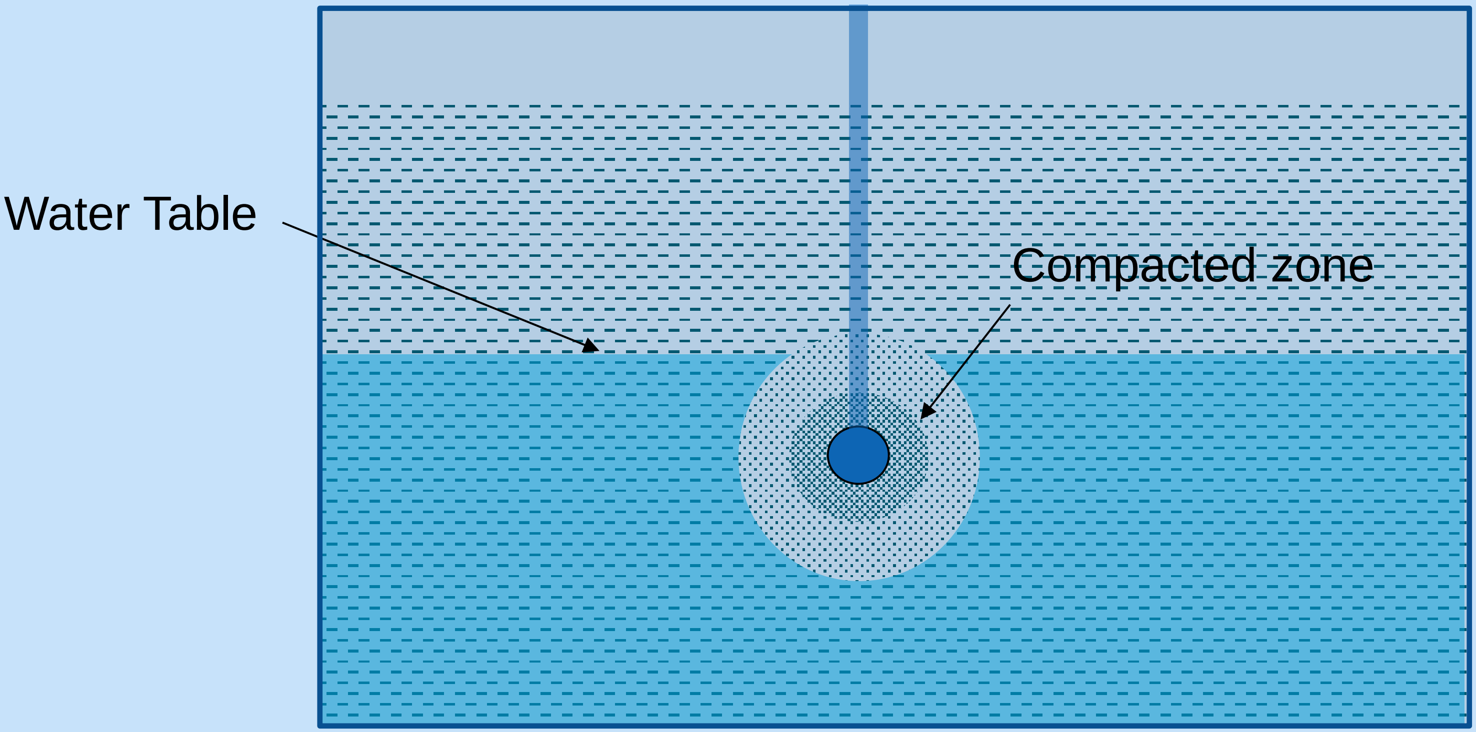
Rock Joint Grouting



Permeation Grouting



Compaction Grouting



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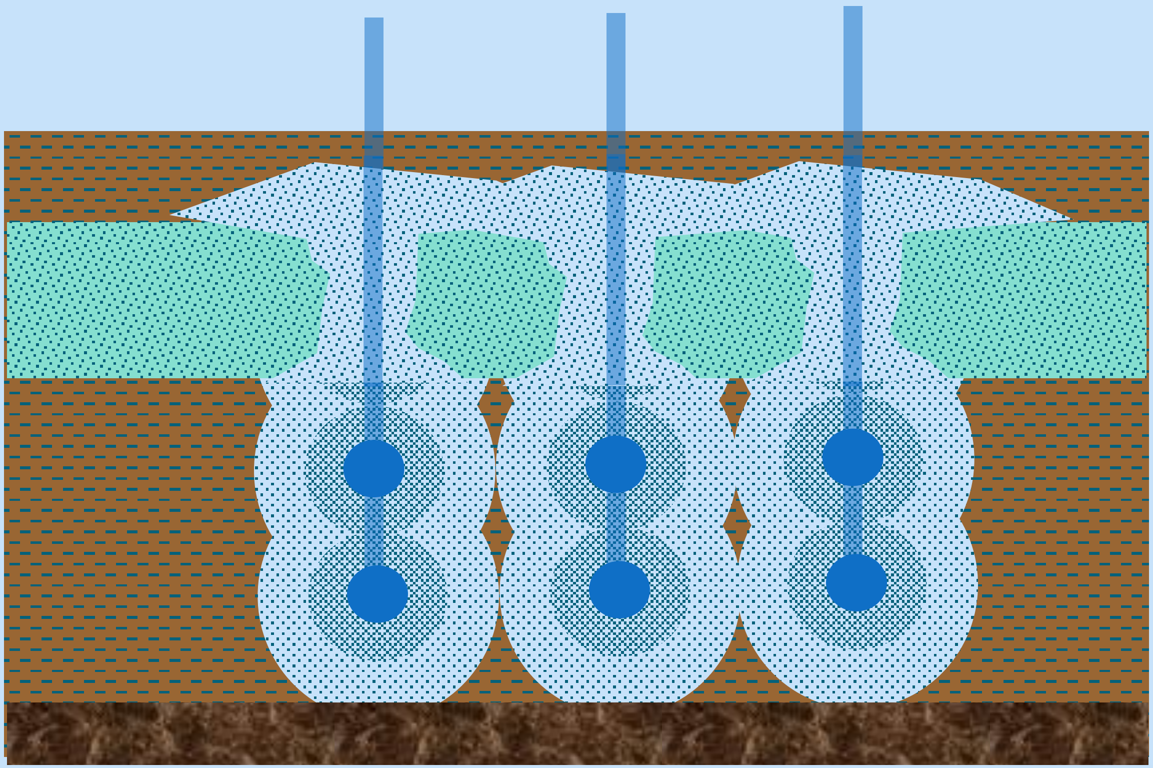
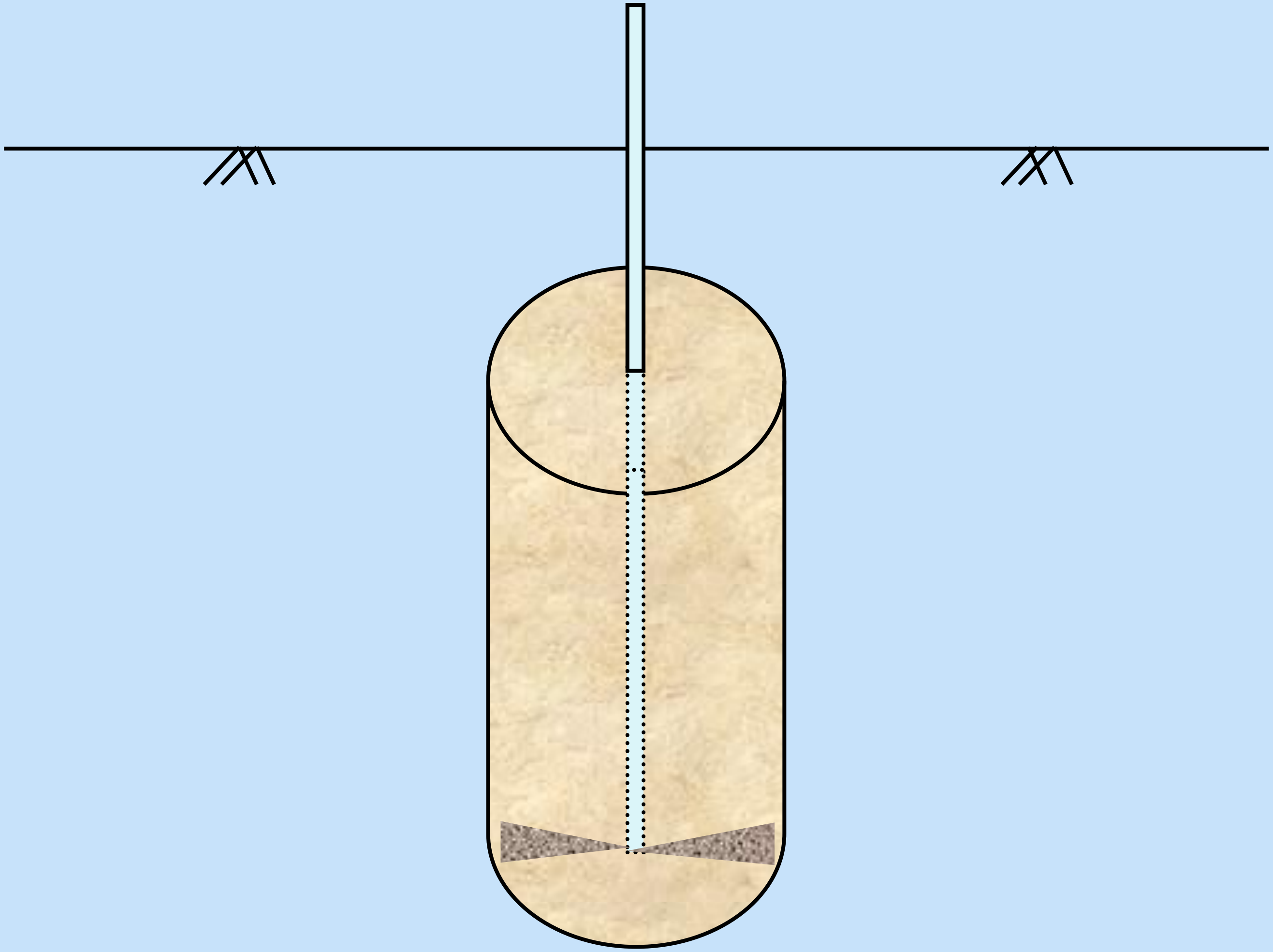
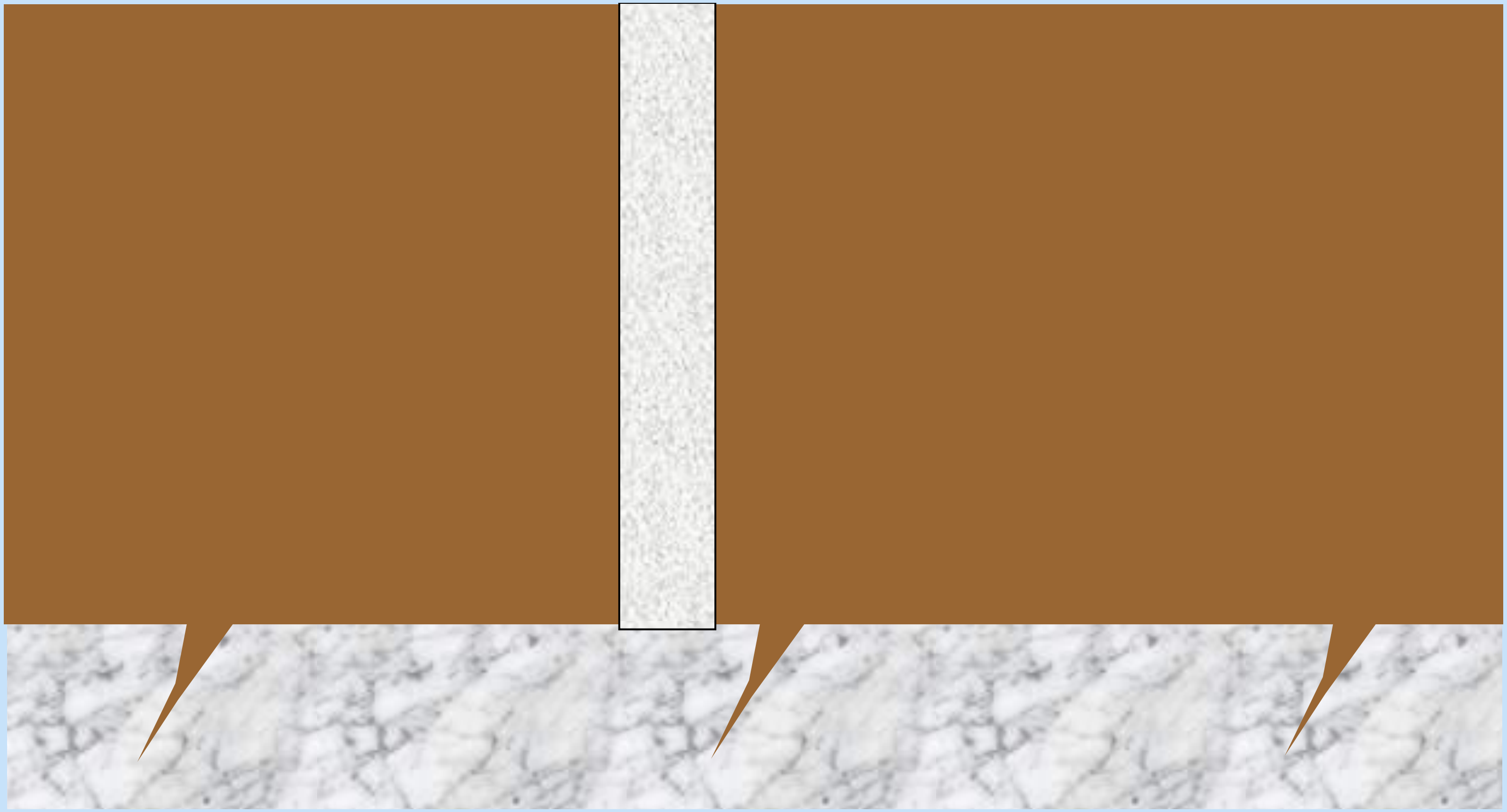


Jet Grouting



Deep Mixing

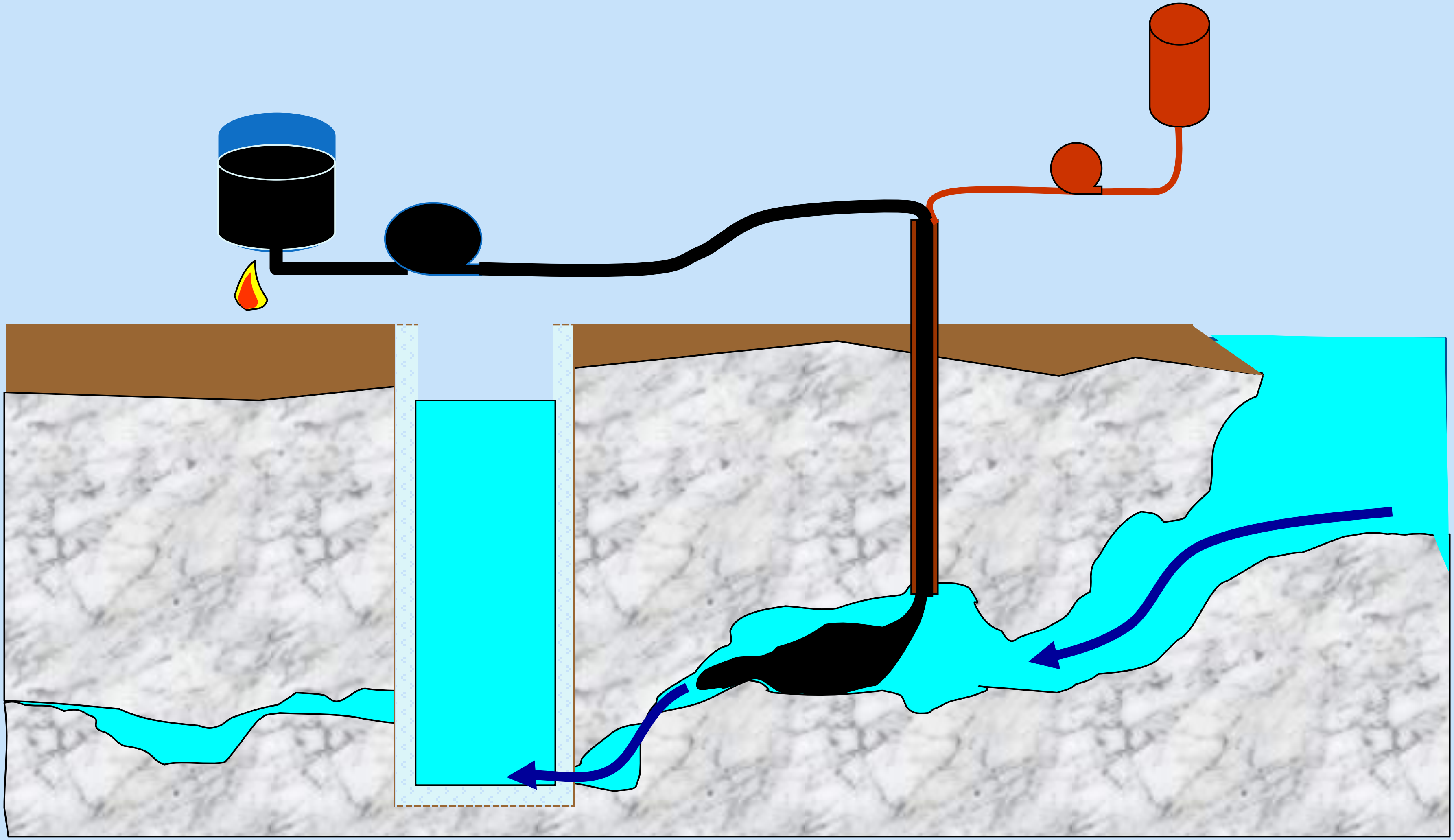


Deep Mixing

Hot Melts

- Injection of a molten solid that solidifies in the ground
- Predominantly Bitumen
- Used to control high volume water flows

Hot Bitumen Grouting



Verification is Important

- Verification provides a basis for:
  - Measuring success
  - Payment for performance based contracting
  - Modifying the means and methods during construction
  - Satisfying third parties
    - Insurance companies
    - Financial institutions
    - Owners

Planning for Verification

Verification Objective

1. *Liquefaction resistance*
2. *Cutoff of Seepage*
3. *Resultant bearing capacity*
4. *Settlement Reduction*
5. *Structural support (i.e. underpinning)*

Factors Monitored

1. *Soil Stiffness*
2. *Presence of grout*
3. *Grout Stiffness*
4. *Overall ground strength*
5. *In-Place grout quality*
6. *Resultant Permeability*
7. *Size and shape of injected mass*
8. *Temperature*

Using Correlated Properties

Desired Properties

- Defining limits of grout intrusion
- In-situ grout compressive strength
- Settlement

Correlated Properties

- Electrical conductivity/resistivity
- Magnetic properties
- Seismic wave velocity
- Blow count resistance
- Ground movement
- Acoustic emissions
- Stiffness
- Static penetration resistance

Using Correlated Properties

Desired Properties

- Hydraulic Cutoff
- Permeability Reduction
- Sealing Leaks

Correlated Properties

- In situ permeability
- Groundwater gradients
- grout permeability
- Electrical conductivity/resistivity
- Acoustic emissions

Basis for Verification

- In situ values will differ from ex situ test results
- Variability in the formation will result in variability of the grout injection and properties
- Recognize that in many instances it will not be possible to measure the property of concern

Consider Verification During Pre-Design

- Subsurface Characterization
  - Forms the baseline from which to assess improvement
  - Provides insight into appropriate verification methods
  - Identifies parameters essential for verification
- Consider multiphased investigation to permit focused investigation prior to final design
- Helps to select verifiable grouting methods

Verification Considerations in Investigation

- Characterize site variability or outstanding uncertainty of site conditions
- Special parameters needed for verification (electrical, chemical, geophysical, etc)
- Improve detail of characterization to anticipate potential verification problems
- May use special tools and techniques
  - Geophysics – seismic, resistivity, gravimetric, etc.
  - In situ tests – CPT, SPT, DMT, Permeameters, etc.
- Investigation may need refinement as the design develops

Investigation Should Identify Parameters for Verification of Grouting

Understanding how grouting may alter any of these parameters is essential to planning verification

- Permeability
- Grain Size Distribution
- Compressibility
- Void Ratio/Relative Density
- Electrical Resistivity
- Seismic Wave Velocity
- Soil Contrasts
- Soil/Groundwater Chemistry

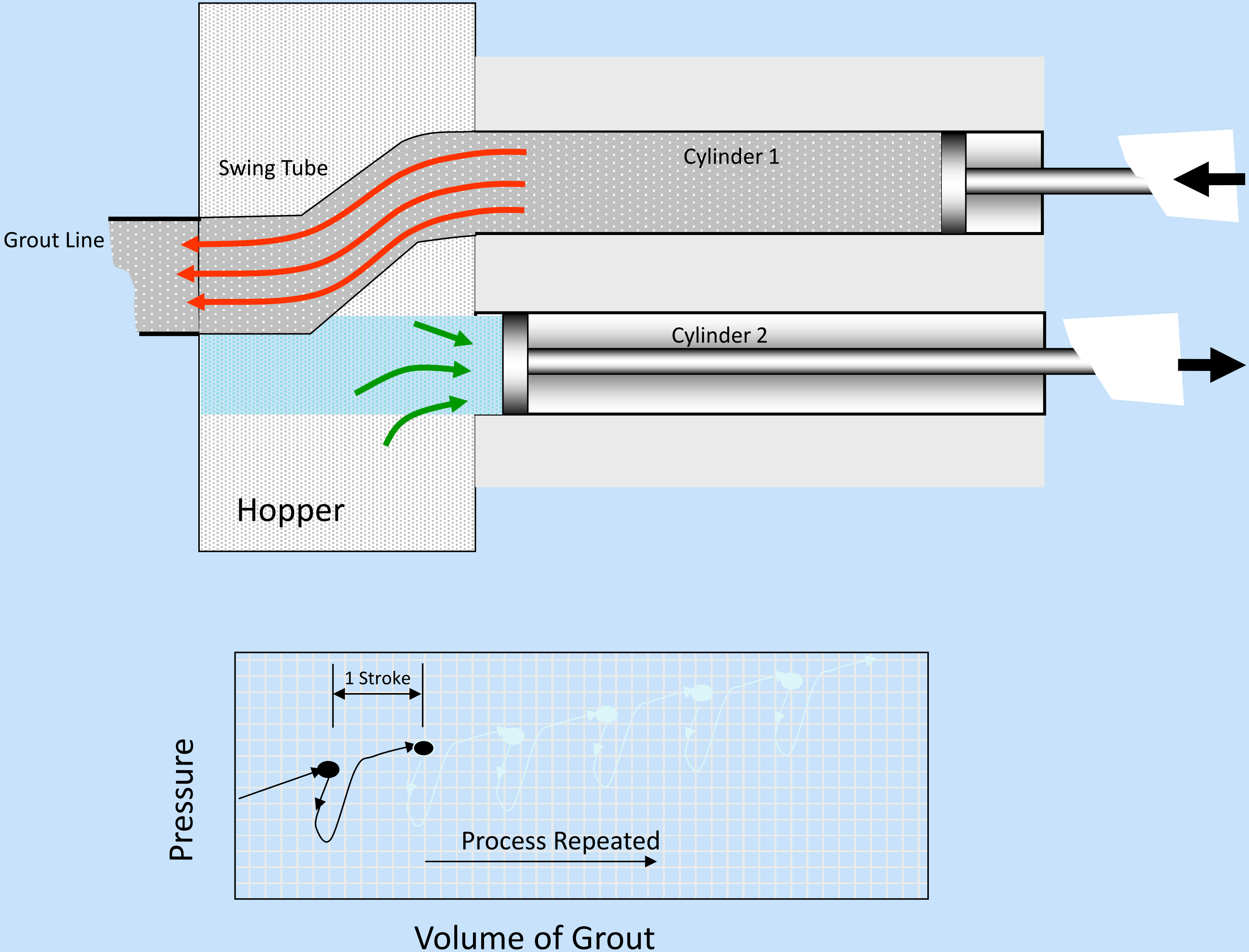
Basic Fundamentals to Begin Planning Verification

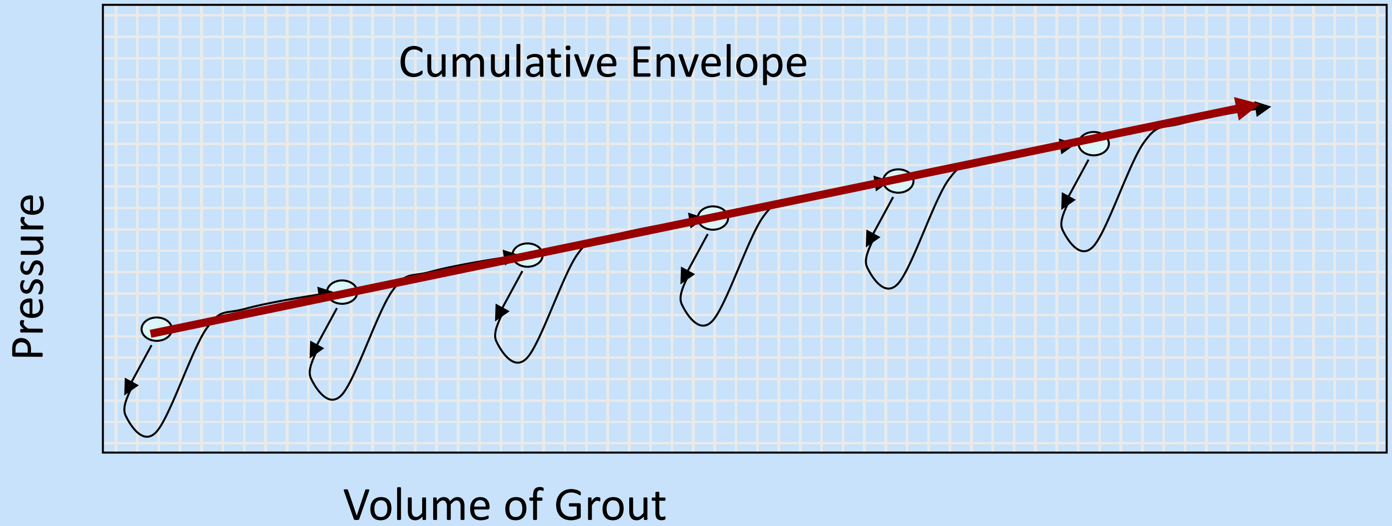
- Physical limits of strata
- Groundwater level and flow
- Range of variability
- Stratification
- Subsurface structures
- Obstructions (boulders, rubble, etc.)

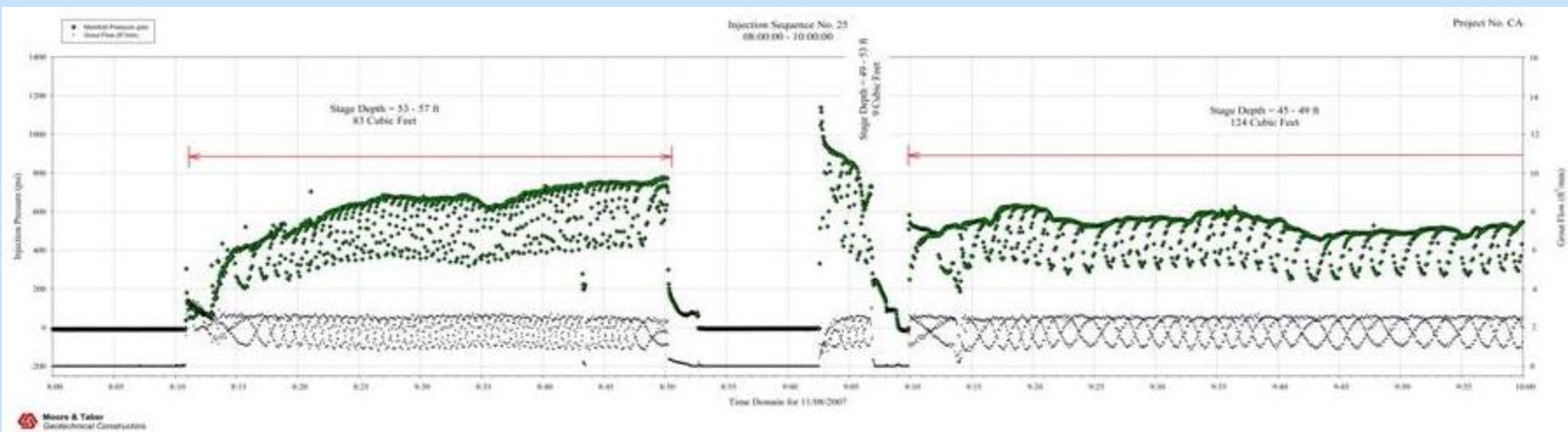
Verification Tools and Techniques

Grouting as Verification

- Range Detection Pipes for Jet Grouting
- Deflection measurements during grouting
- Pressure/volume relationships
  - Aparent Lugeon Method
  - LMG Pressure Response
- Digital real-time methods are now commercially available


Swing Tube
Cylinder 1
Grout Line
Cylinder 2
Hopper
1 Stroke
Process Repeated
Pressure
Volume of Grout





Courtesy Moore and Taber

Direct Sampling

- Coring
- Test Excavations
- Directly measure properties of sampled materials
- Some materials difficult to sample
- May not measure intended objective
- Consider spatial variability vs. sample size

Coring

- Coring success is material dependent
- Core deviation from grout mass may be a problem and should be validated with inclinometer
- Cored samples can be tested in laboratory

Coring Jet Grouted Fill

Physical Examination

- Appropriate where the presence and distribution of the grout is an effective indicator of performance (i.e. inclusions)
- Requires excavation of grout mass or extraction
- Usually destructive
- Appropriate for Test Sections for Critical Applications and for Support of Excavation

Element Extraction

Direct Examination

Photo Courtesy of Sam Bandimere

Test Excavation

In Situ Modulus Tests

- Includes DMT and PMT
- Measure deflection under lateral or radial loading
- Good for some sands, silts, clays
- Can be correlated to density
- Affected by residual stresses

Settlement Plates/Points

- Measure elevation or change in elevation at a given point
- Usually used to measure heave or settlement
- Accuracy depends on the method of survey
- Where settlement control is the goal, this is very effective, but after the fact

Load Testing

- Usually for structural elements
- Can be done on subgrades with plates
- Directly measure deflection under loading to calculate modulus
- Can measure bearing capacity if failure is achieved

Penetration Resistance

- Commonly used - Cone Penetrometer and SPT
- Relatively inexpensive
- Accuracy and repeatability dependent on method and personnel
- Widely accepted
- Can be correlated to density
- Not many correlations for modified ground
- Influenced by residual stresses

Density Tests

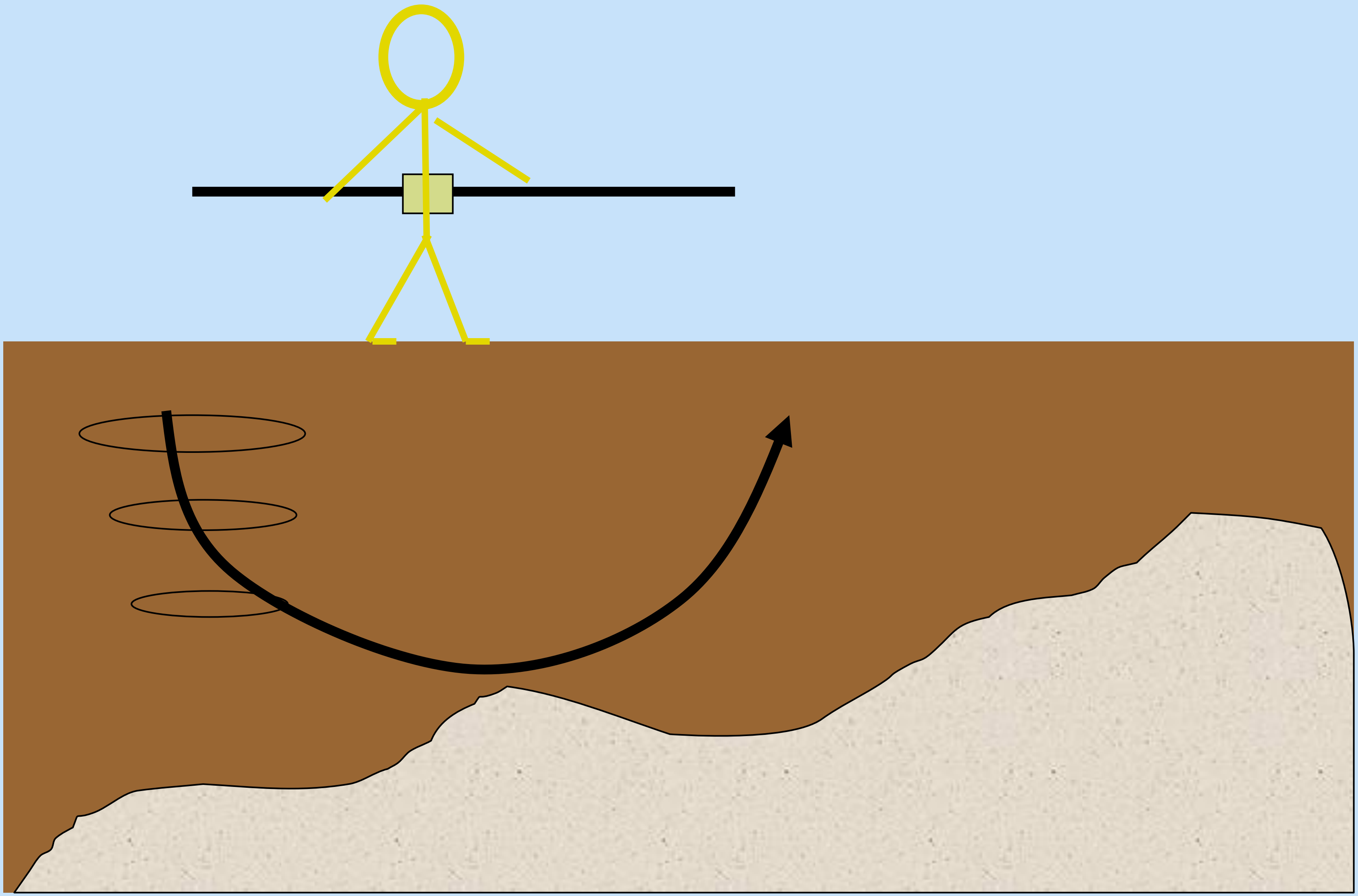
- Include - Sand Cone, Rubber Balloon, Drive Cylinder Method, Nuclear Densometer
- Require excavation or exposed surface
- Nuclear density gage relies on empirical correlation of radiation transmission to density
- Reliable but difficult to use

Plate Load Test

- Appropriate for applications where changes in the strength of the soil, grouted soil is measurable and useful for evaluating grouting effectiveness
- Measurement is limited by the plate size

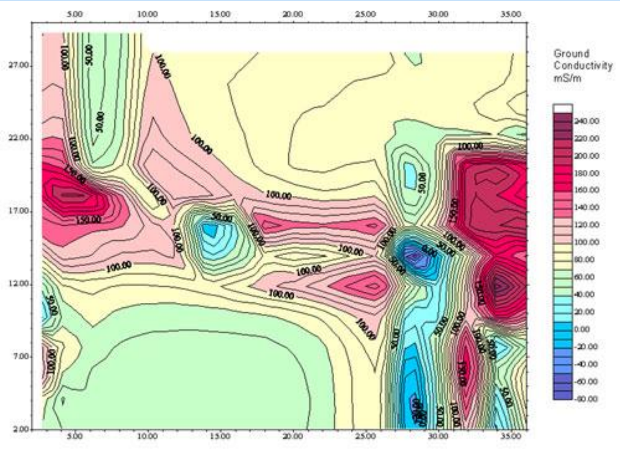
Geophysical Methods

Terrain Conductivity

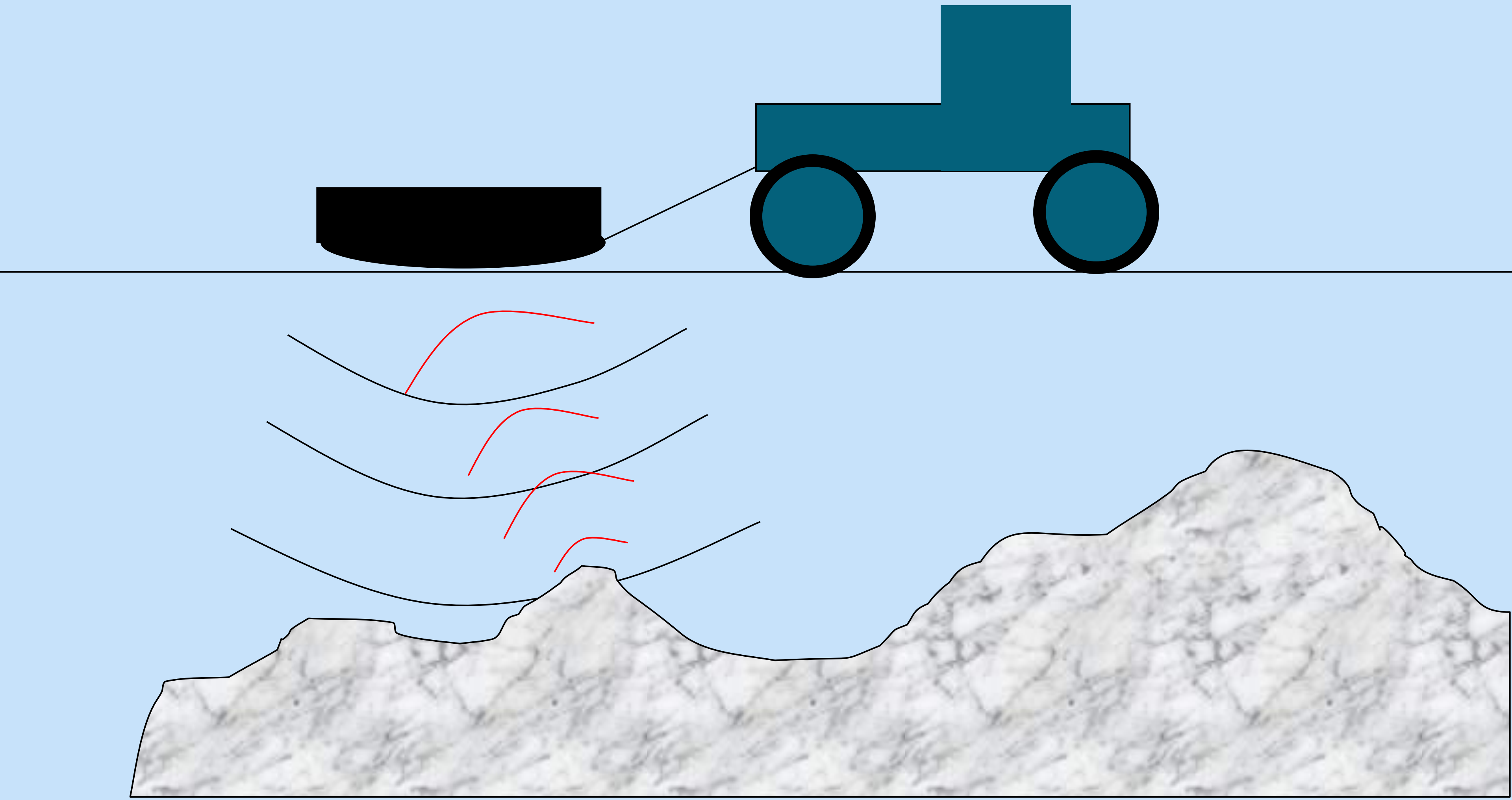


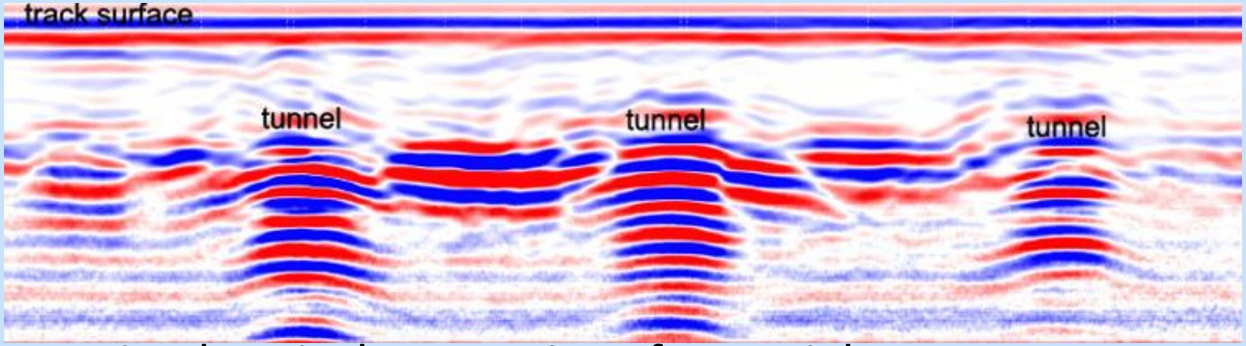
Terrain Conductivity

- Electro-magnetic method
- Coil induces alternating electric current in the ground
- Second coil detects magnetic field generated by alternating current in the ground
- Conductivity varies inversely to the ratio of the primary to secondary coil field strength and the square of the distance between the coils



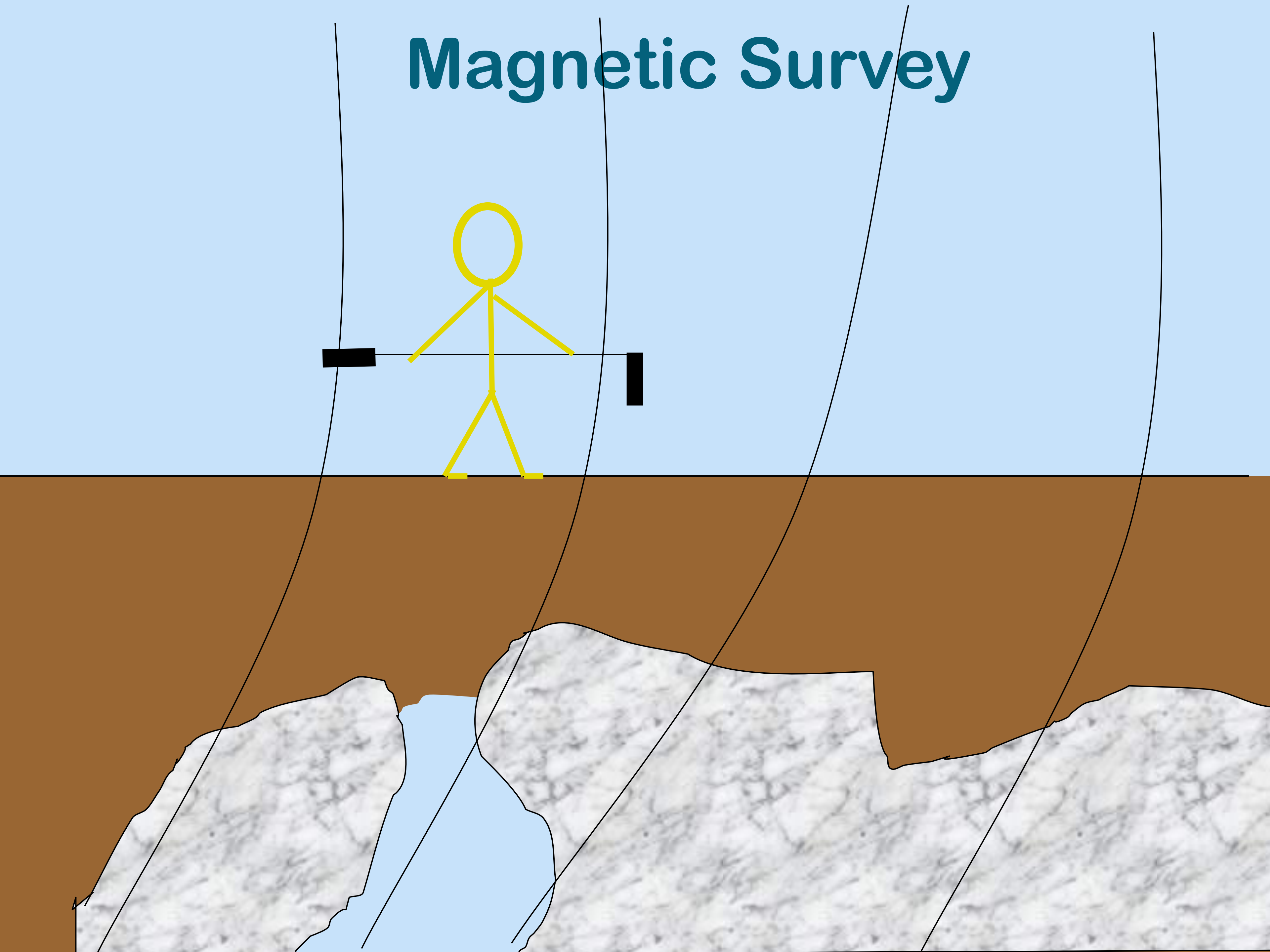
Ground Penetrating Radar





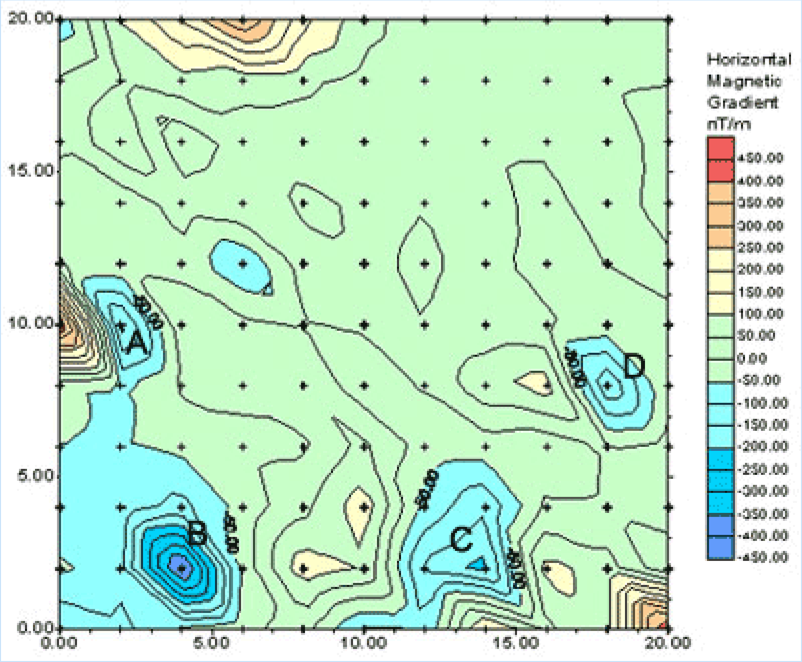
- Pros
  - Identifies contrast in electrical properties of materials
  - Low cost
  - Good shallow resolution in granular soils
  - Voids are high contrast objects for GPR and show up well
- Cons
  - Limited depth
    - Most soils - several feet
    - Optimal conditions – 10-15 feet
  - Will not work in high attenuation soils
    - Clay
    - Micaceous soils and rock
  - May not resolve grout

Magnetic Survey

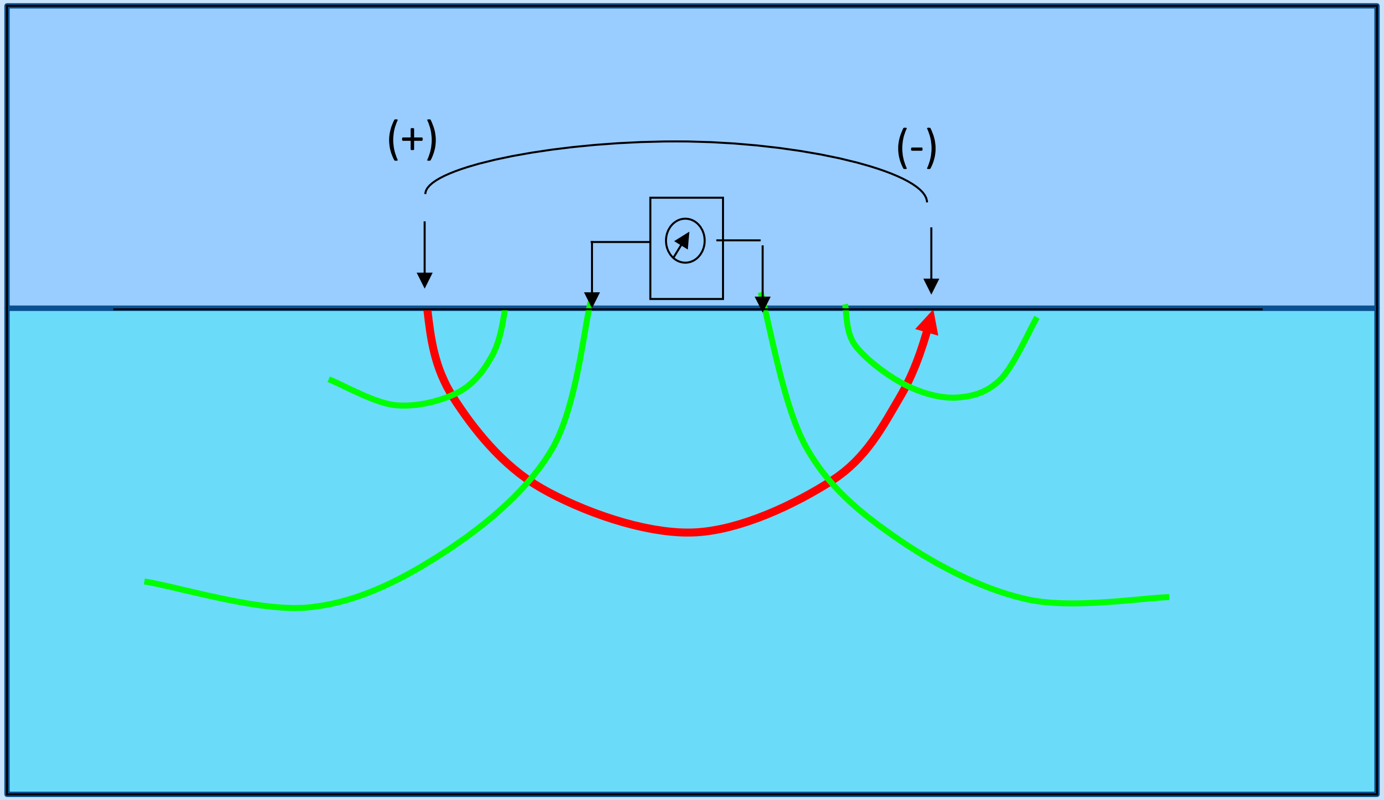


Magnetics

- Utilize Magnetometers and Gradiometer to measure changes in the earth's magnetic field
- The magnetic field intensity is measured on a grid, plotted and contoured
- Anomalies indicated by steep gradients or closed contours
- Interpretation can be difficult
- Same sensitivities as Terrain Conductivity
- Best for metallic or magnetically constrasting materials (additive to grout may be advisable)



Resistivity

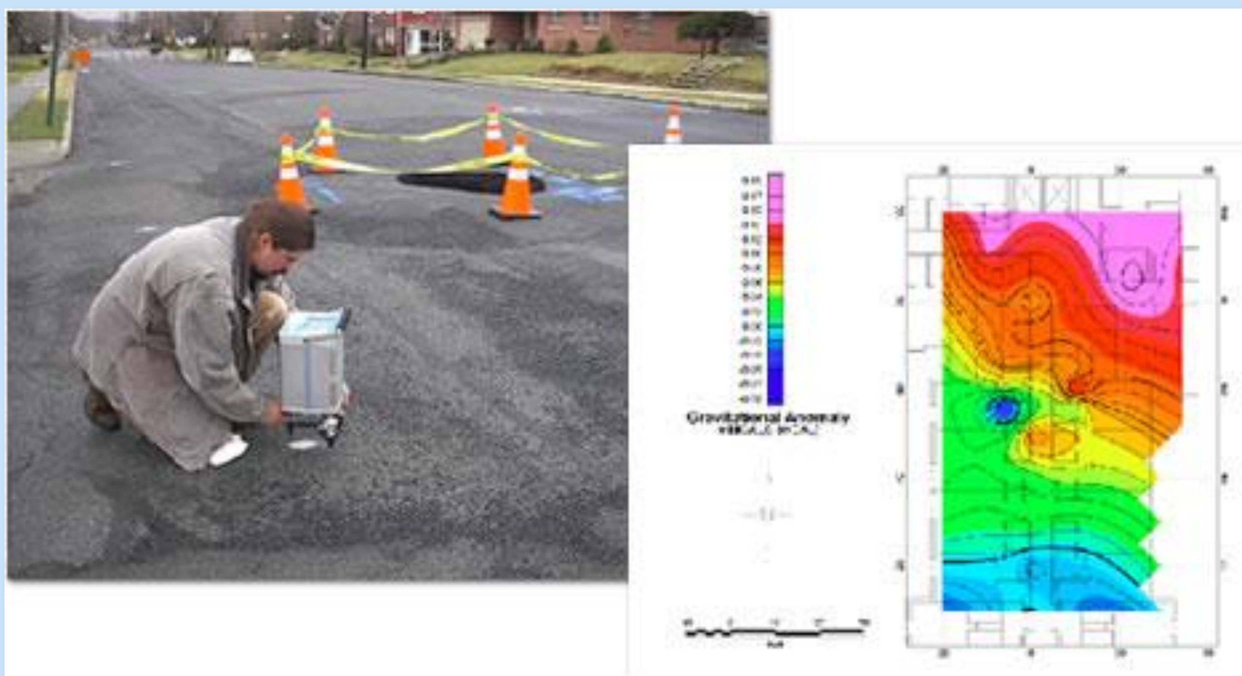


Electrical Resistivty

- Applies voltage across two electrodes
- Measures resistance across inner electrodes
- Depth is dependent upon electrode spacing
  - Larger spacings equal larger depth
  - Result is average over depth
- Only useful where there are contrasts in the electrical properties of the materials to be tested (e.g. grout and soil, soil and rock, grout and rock, grout and groundwater, etc.)

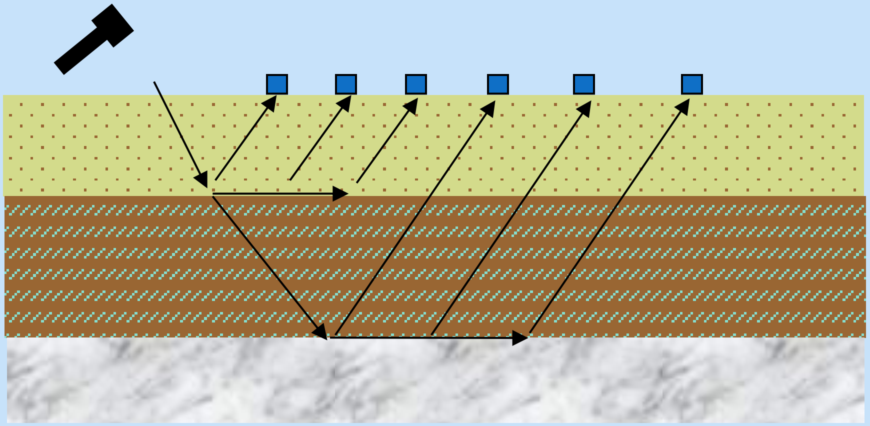
Micro-gravity

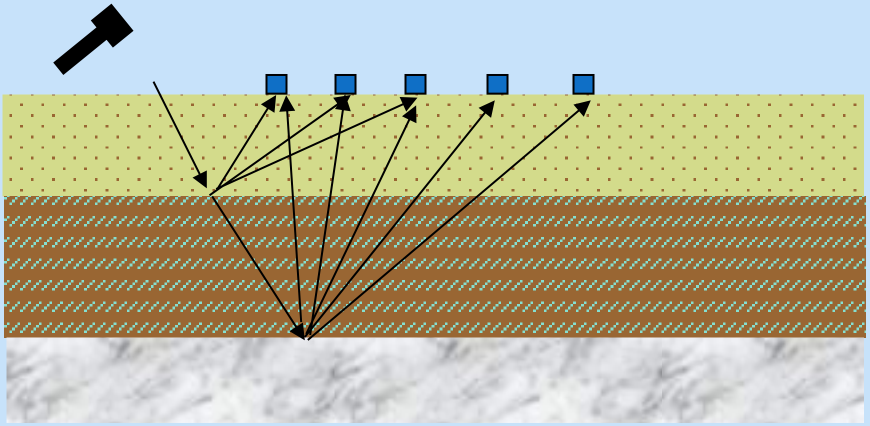
- Measures the strength of the earth's gravitational field at discrete points
- Plots results to identify areas of low gravity that imply deeper rock, or voids
- Test is sensitive to vibration
- Requires corrections for terrain
- Good for resolving large voids or areas of voids in otherwise sound rock
- Relatively high cost; readings are slow



Seismic

Refraction





Reflection

Seismic Refraction

  - Detects contrast in stiffness of materials
  - Reasonable cost
  - Good resolution in most materials
  - Best if done as a before and after
  - Easy to identify large soft zones or voids
- Limitations
  - Cannot detect soft layers beneath stiff layers
  - Difficult to interpret if highly irregular surface (pinnacles can lead to pulse inversion)
  - Resolution decreases with depth
  - May not be able to resolve grout
  - Traffic and construction produce noise that can limit quality of results

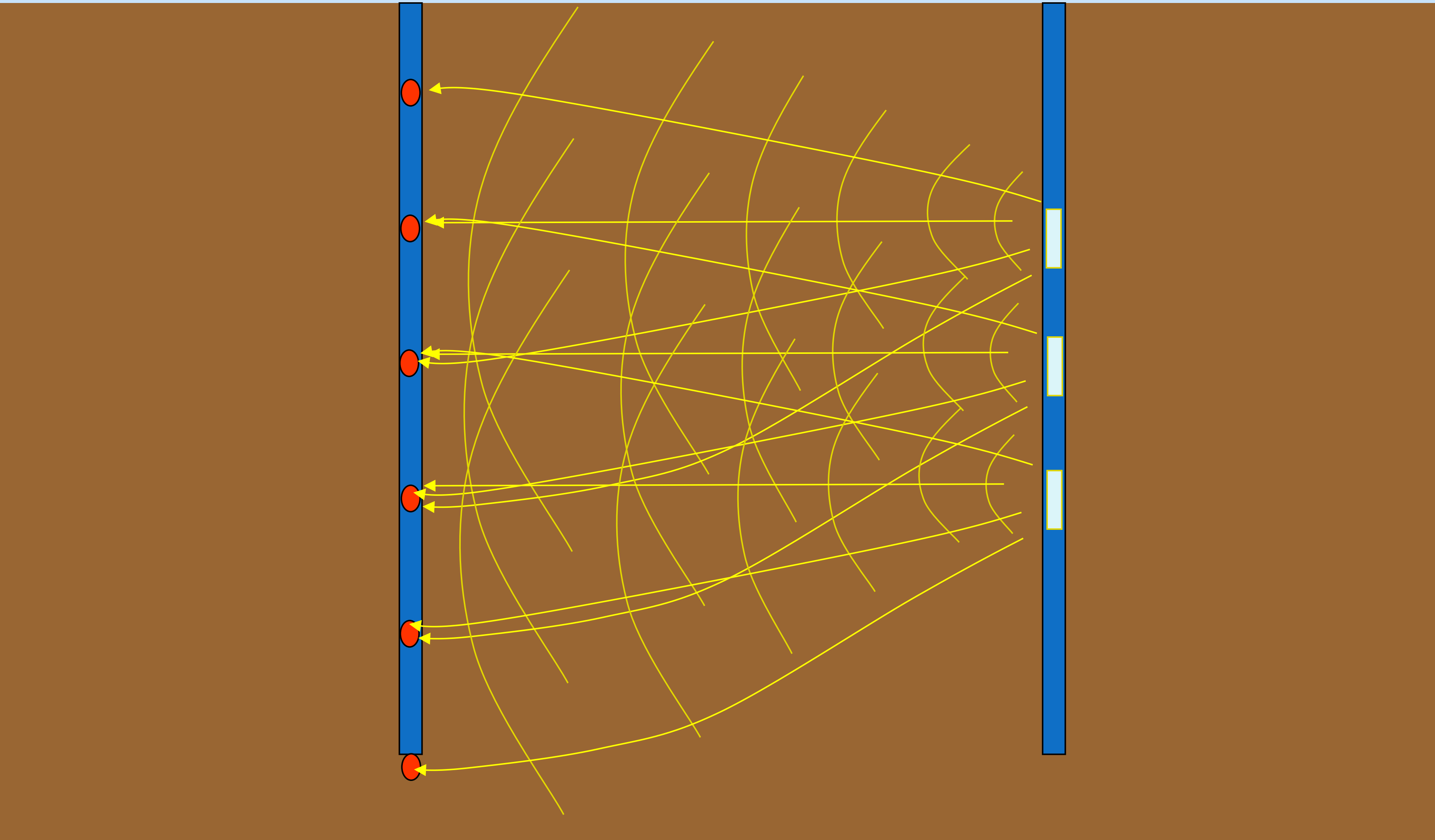
Seismic reflection

- Pros
  - Good resolution in most materials
  - Measures soil/rock stiffness
  - Easier to interpret (Voids are always low velocity zones)
  - Effective at greater depth than refraction
  - Can detect soft layers beneath stiff layers
- Cons
  - Cost – requires large number of data points
  - Difficult to interpret if highly irregular surface (pinnacles can lead to pulse inversion)
  - Resolution decreases with depth
  - Small voids in high velocity material may be invisible
  - May not be able to resolve grout

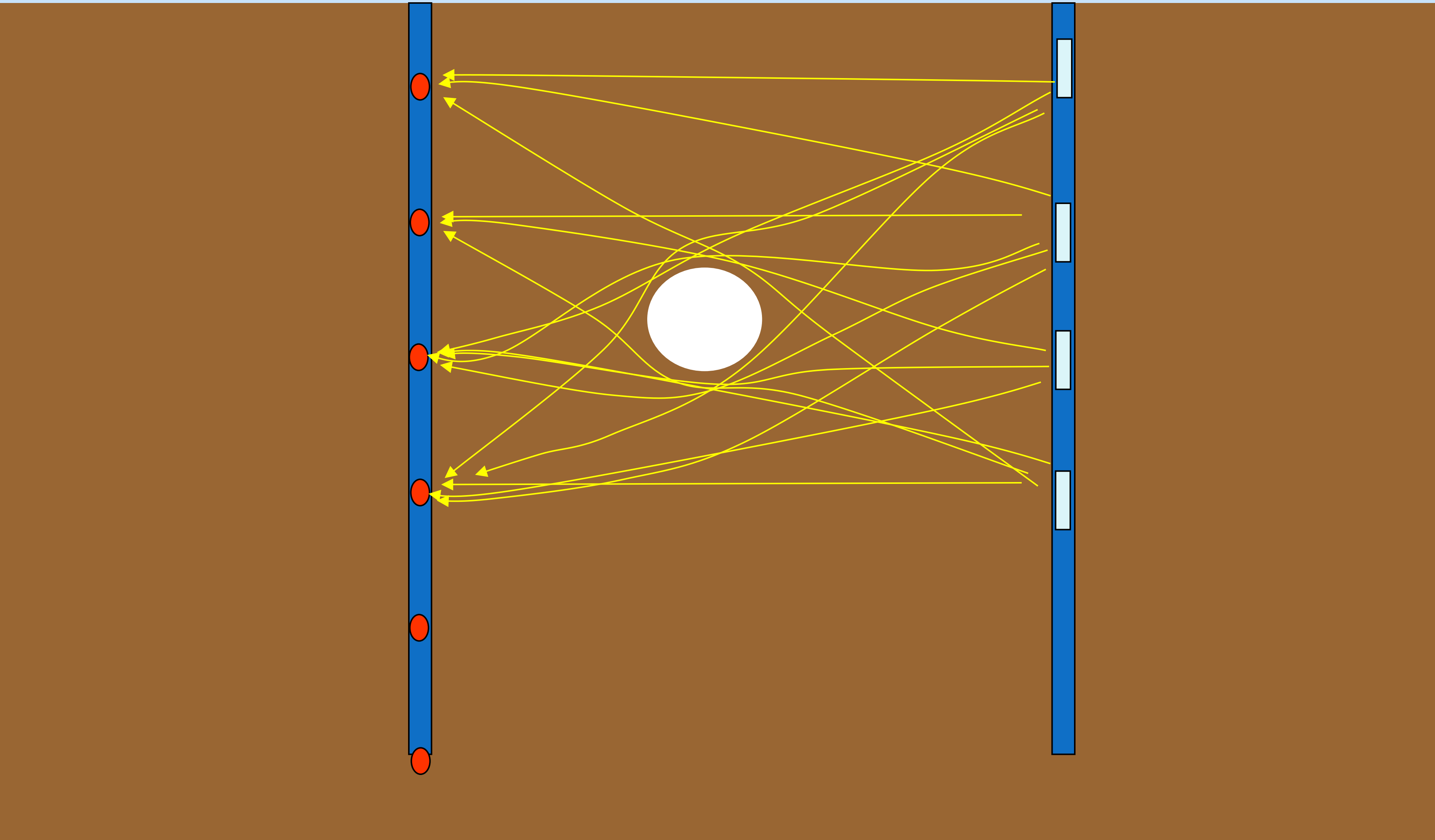
Borehole methods

- Virtually all of the methods discussed can be done in and between boreholes
  - Vertically within boreholes (borehole logging methods)
  - Diagonally from ground surface to borehole (up-hole or down-hole methods)
  - Horizontally between boreholes (cross-hole methods)
- Many limitations of methods can be overcome by adjusting spacing or depth of boreholes
- Borehole drilling and sampling gives a true answer at each borehole that can be used to calibrate the geophysical data

Crosshole Geophysics



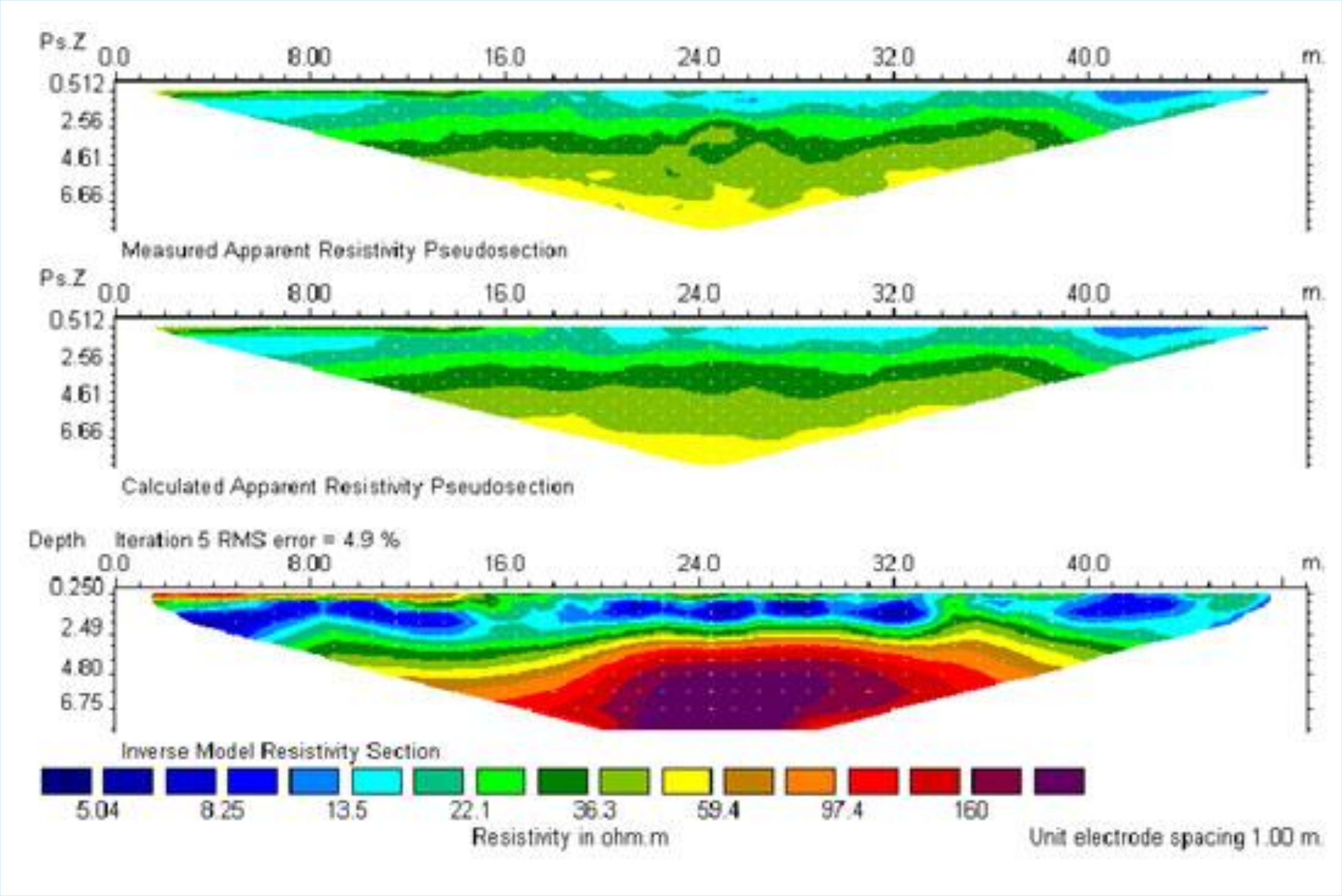
Crosshole Tomography



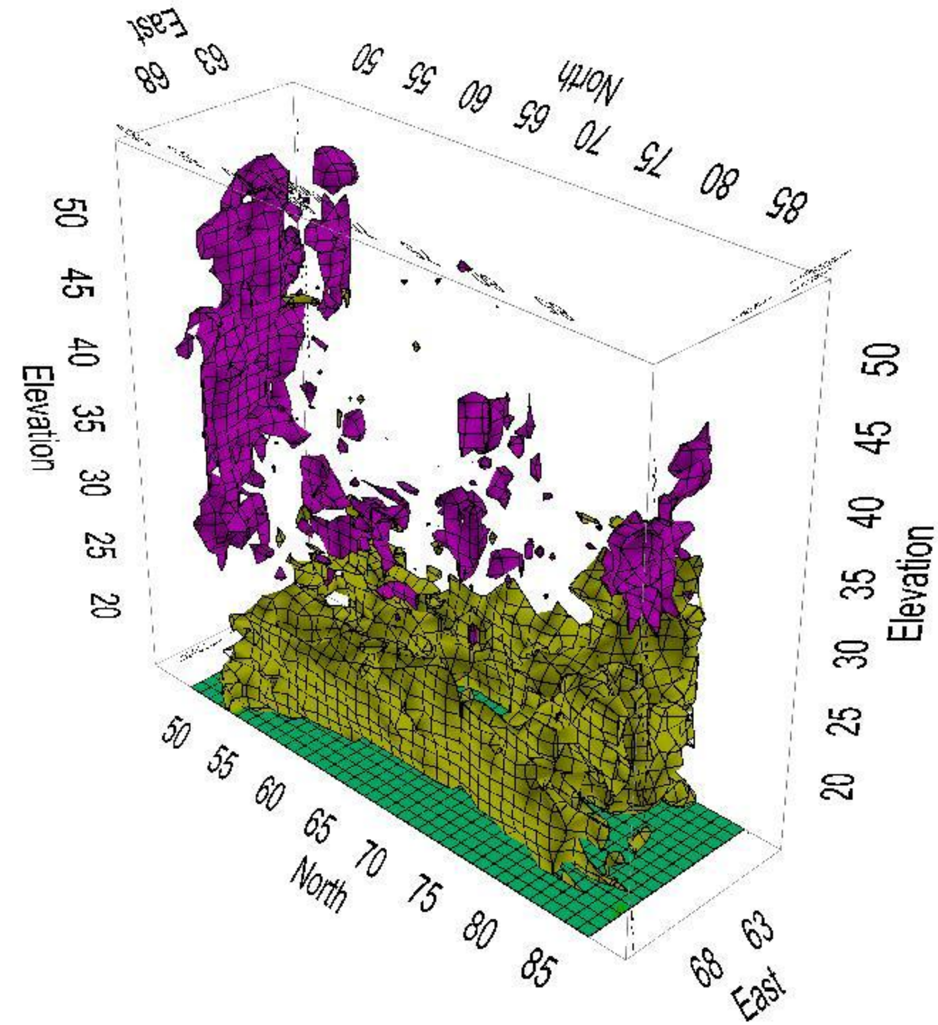
TOMOGRAPHY

- A process of imaging based on wave phenomenon. (similar to a CAT Scan)
- A graphical numerical model is created to produce the same result as the data collected
- This requires a large amount of data
- A forward model is used to assess the likelihood of success
  - A model of expected conditions is created
  - The ability of the system to detect the conditions is tested by simulation
  - The resulting information is used to select the appropriate methods and arrangement for the field test.

Resistivity tomography



Seismic Tomography



Multiple Tools

- There is no magic bullet
- Each site is unique
- Combining methods of verification can produce a superior result
- *Grout monitoring together with a sampling method and a geophysical method can provide a more complete picture*

Planning for Verification

1. Identify need for grouting early, *preferably during investigation stages*
2. Identify goals of grouting and what it is possible and necessary to verify
3. Determine the mechanism and properties of the grout in-place as compared to the substrate
4. Select methods that can detect relevant properties
5. Use them in combination to best effect

Planning for Verification

7. Use a qualified inspector
8. Record and report <u>everything</u>
9. Plan on the unexpected
    a) Evaluate the results as the work progresses
    b) Adjust methods as needed to assure good results

THANK YOU!