



Detailed Inspection Training

Geotechnical and Structural Evaluations



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A yellow tracked drilling rig is positioned on a grassy area with fallen leaves. A worker in a light-colored jumpsuit and hard hat stands near the rig. In the background, there is a silver trailer and some trees under a blue sky with light clouds. A grey vertical bar is visible in the upper right of the image.

Agenda

1. Introduction to Geotechnical and Structural Evaluations
2. Field Investigations
 - Geophysical Surveys
 - Test Borings, Cone Penetration Test Soundings, etc.
 - Structural Field Testing
 - Instrumentation Installation and Monitoring
3. Laboratory Testing
4. Data Interpretation
5. Geotechnical and Structural Analyses
6. Next Steps



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Introduction to Geotechnical and Structural Evaluations



Introduction to Geotechnical and Structural Evaluations

- Determine and understand the soil and rock conditions for design and to ensure the stability of foundations and structures.





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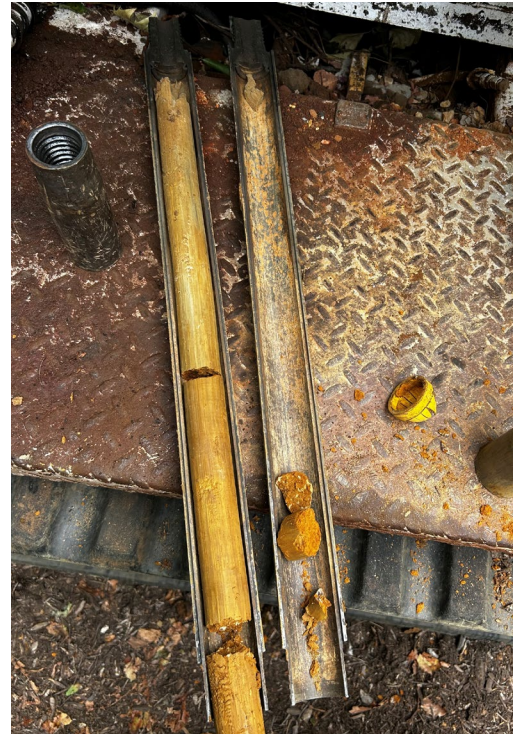
Field Investigations



Field Investigation

Characterize Site, Identify Potential Construction Problems, and Aid in Design:

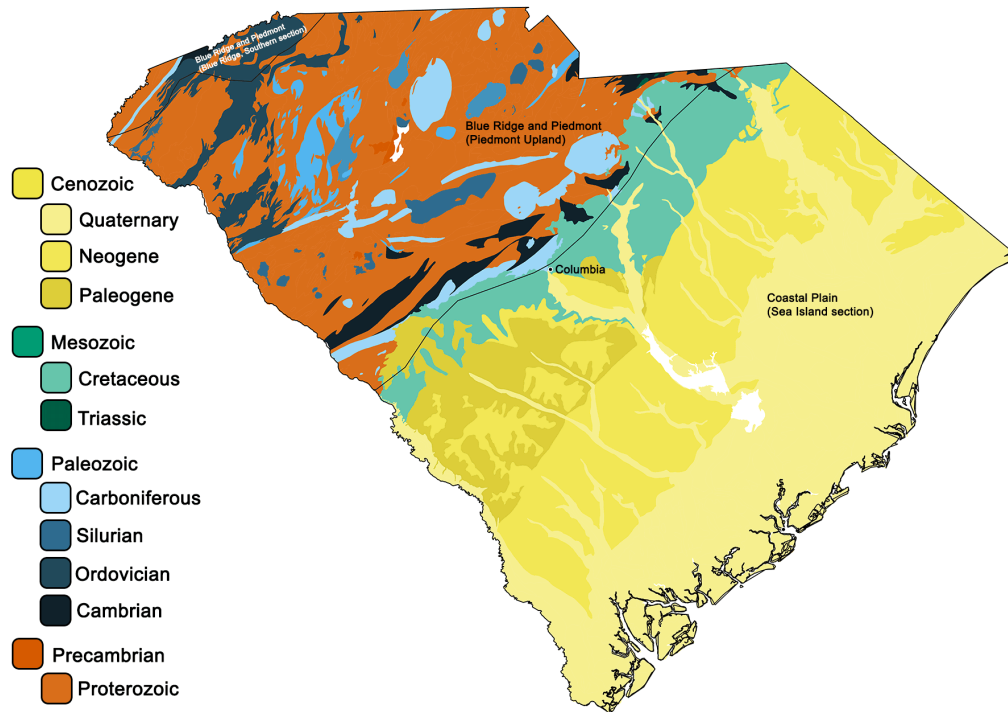
- Soft / Loose Soils
- Organic Soils
- Degrading Soils or Rock
- Shrinking / Swelling Clay
- Permeable Foundation Materials
- Groundwater Conditions
- Contaminant – Soil and Groundwater



Field Investigation

Surface Explorations:

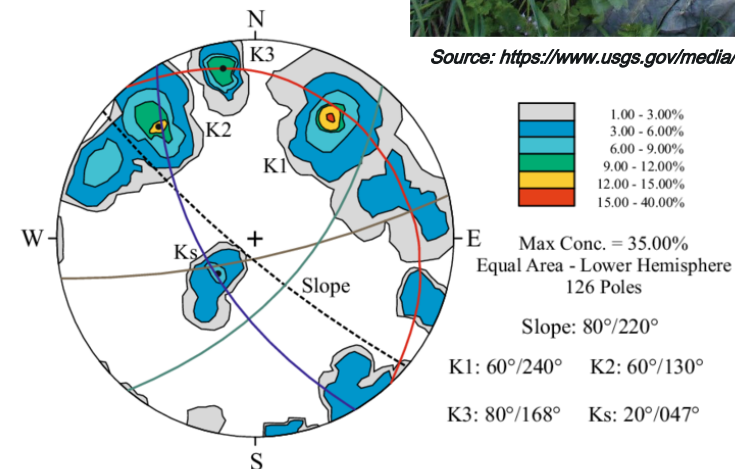
- Site visit, rock outcrops, photogrammetry, geology mapping, etc.



Source: <https://earthathome.org/hoel/maps>



Source: <https://www.usgs.gov/media/images/conoco> -limestone -outcrop

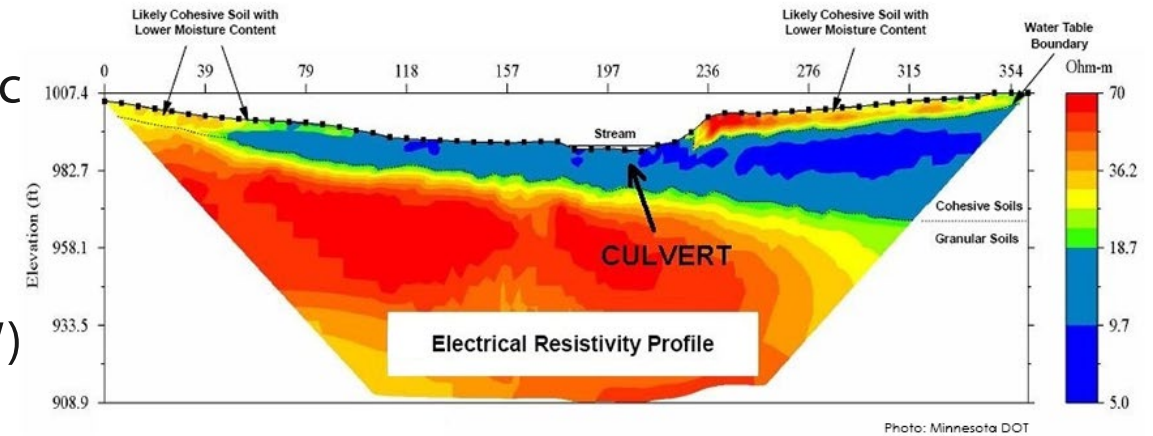


Stereographic Projection

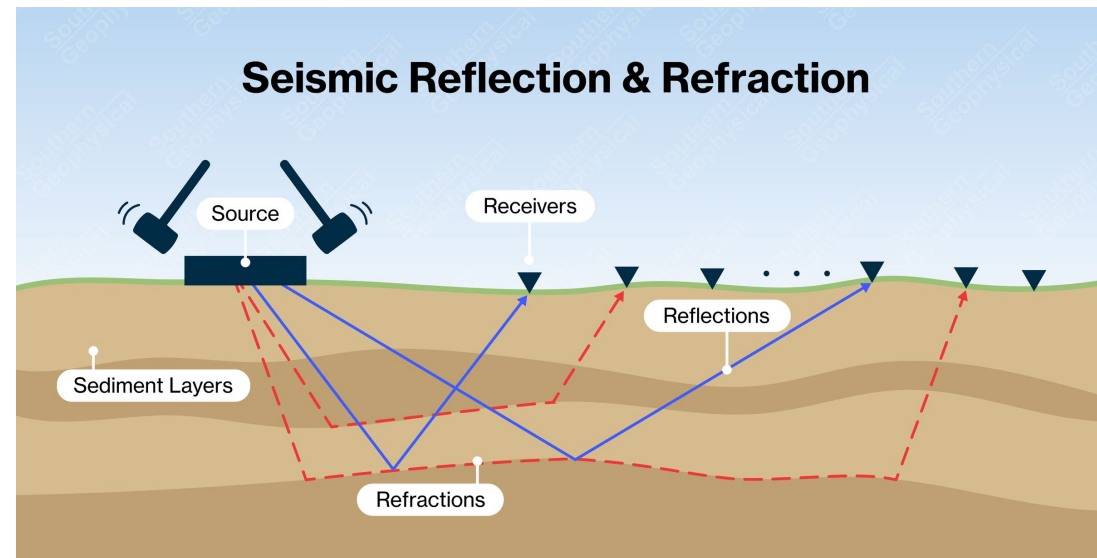
Geophysical Surveys

Typical Geophysical Exploration Methods:

- Wave analyses, gravity analyses, electromagnetic analyses, etc.
- Seismic refraction and reflection
- Multi-Channel Analysis of Surface Waves (MASW)
- Electrical resistivity tomography (ERT)
- Ground penetrating radar (GPR)



Source: <https://blog.cimscemeterysoftware.com/why-do-cemeteries-use-ground-penetrating-radar>



Source: <https://www.southerngeophysical.co.nz/seismic-reflection-and-refraction/>

Geophysical Surveys

— General Overview

Benefits:

Non-invasive and non-destructive

Fast and economical testing

Theoretical basis for interpretation

Applicable to soil and rocks

Limitations:

No samples or direct physical penetration

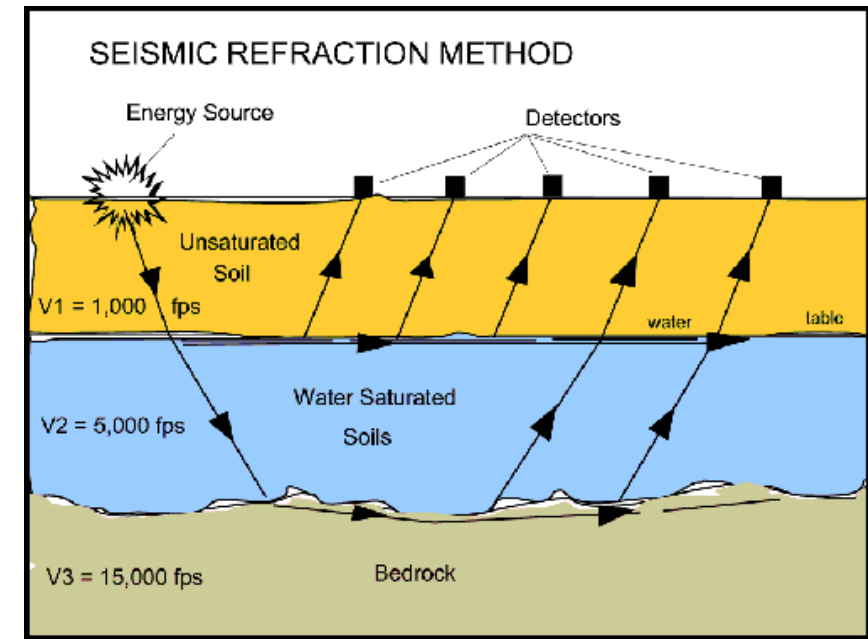
Models require interpretation/calibration based on assumed geology and stratigraphy

Results influenced by water, clay, cementation, inclusions and cavities

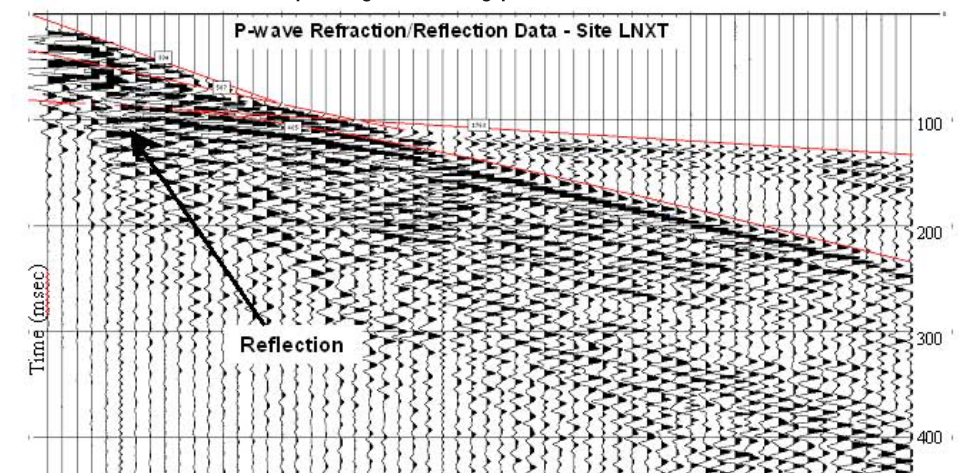
Geophysical Surveys

Seismic refraction and reflection

- Maps contrasts in seismic velocity to estimate rock hardness, density, lithology, degree of fracturing, water content, and weathering.



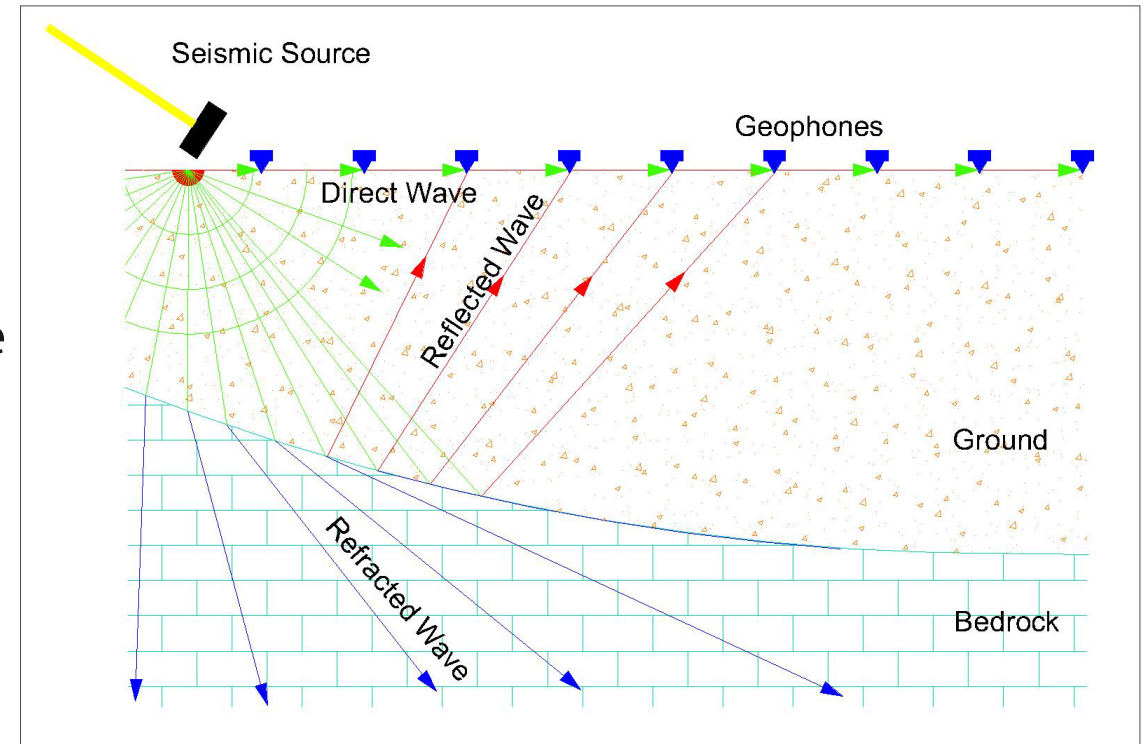
Source: <https://anugrohofisika.blogspot.com/2011/10/seismic-methods.html>



Geophysical Surveys

■ Seismic refraction and reflection

- Maps contrasts in seismic velocity to estimate rock hardness, density, lithology, degree of fracturing, water content, and weathering.
- Utilizes the first incident wave at each geophone to estimate seismic velocity.

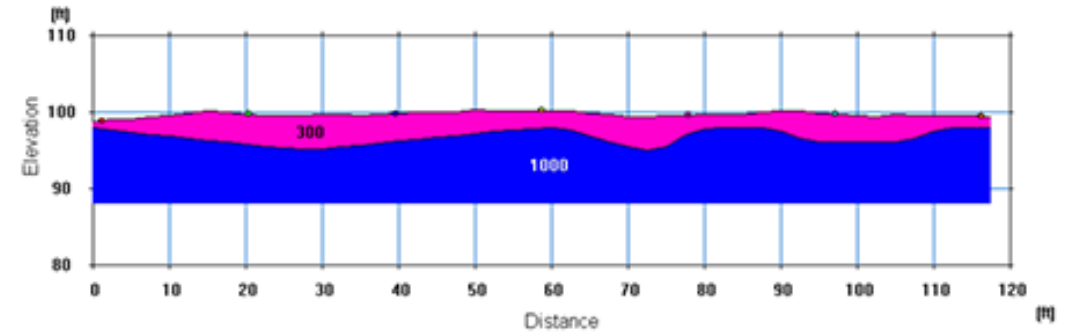


Geophysical Surveys

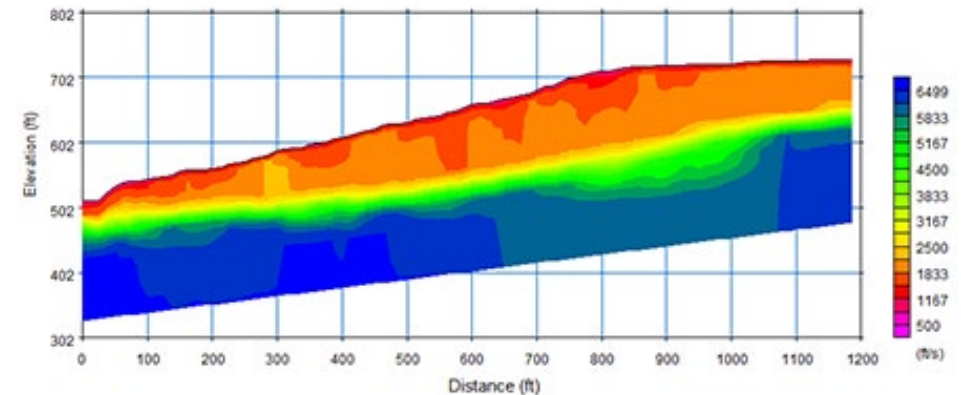
■ Seismic refraction and reflection

- Maps contrasts in seismic velocity to estimate rock hardness, density, lithology, degree of fracturing, water content, and weathering.
- Utilizes the first incident wave at each geophone to estimate seismic velocity.
- Iteratively develops a “layer-cake” soil model, but tomographic inversion can be used.

Layer-Cake Inversion Model



Tomographic Inversion Model



Geophysical Surveys

Seismic Refraction and Reflection

Benefits:

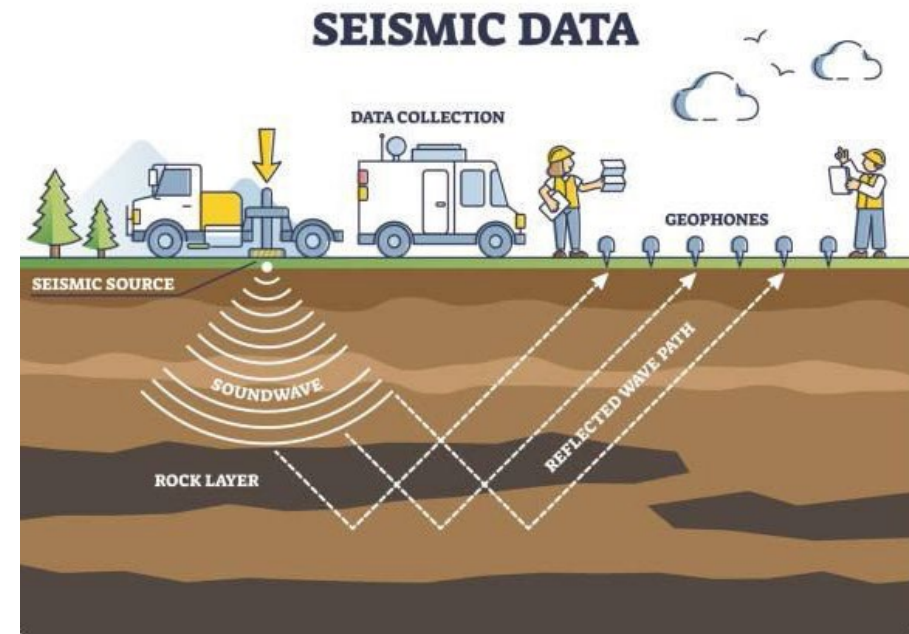
Quickly estimates the rippability of soil/rock prior to excavation

Provides a quick estimate of bedrock topography

Capable of mapping depth to groundwater table

Correlations can be used to estimate elastic moduli and rock quality

Identifies and maps faults



Source: <https://livingconceptengineering.com/wp-content/uploads/2024/04/ser17.jpg>

Geophysical Surveys

— Seismic Refraction and Reflection

Benefits:

Quickly estimates the rippability of soil/rock prior to excavation

Provides a quick estimate of bedrock topography

Capable of mapping depth to groundwater table

Correlations can be used to estimate elastic moduli and rock quality

Identifies and maps faults

Limitations:

Requires that velocities increase with depth. A lower velocity below a higher velocity will not be detected, and will corrupt depth calculations

Seismic source and array dimensions must match the desired depth of penetration

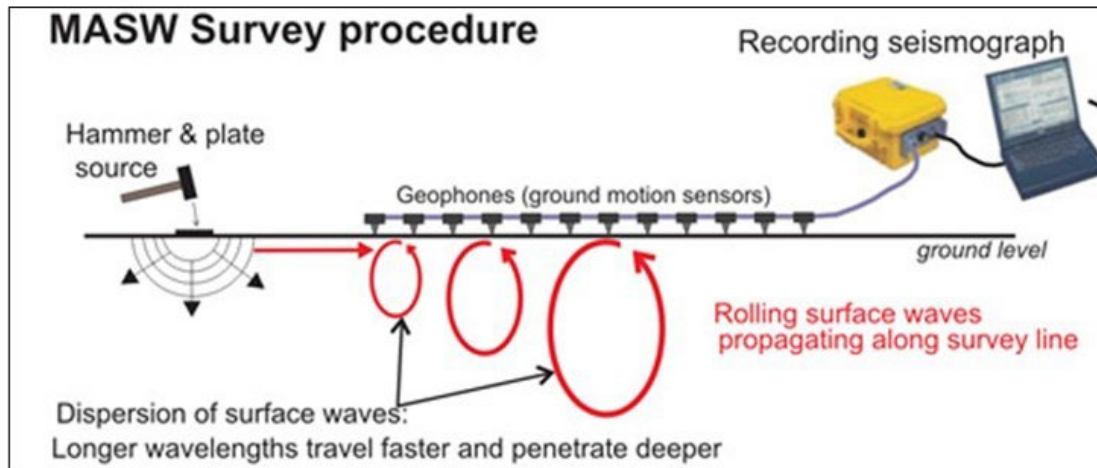
Limited to 3-4 individual layers

Ambient noise can be problematic

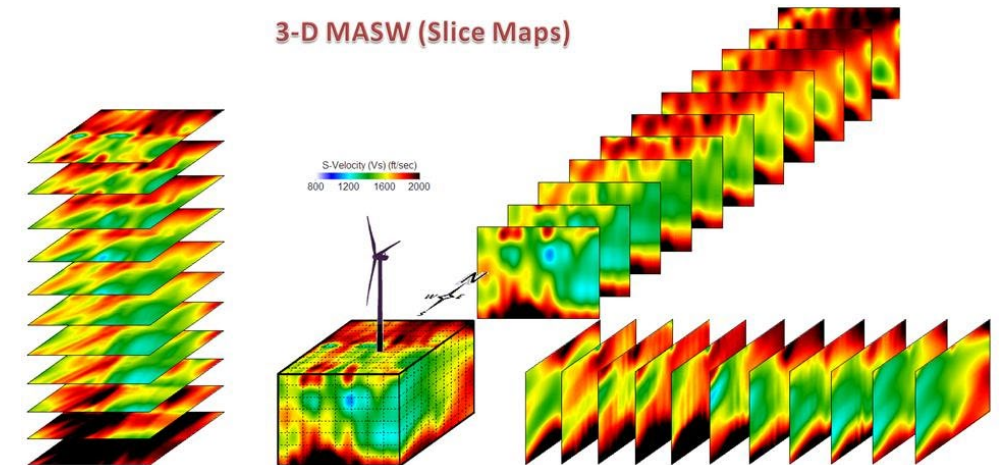
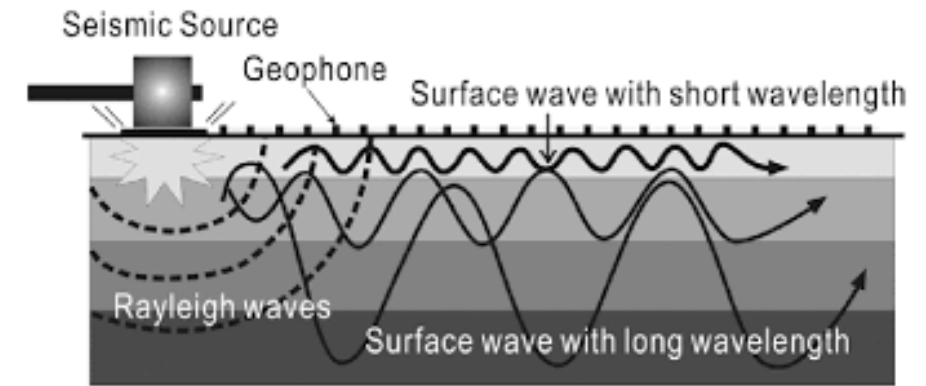
Geophysical Surveys

Multi-Channel Analysis of Surface Waves (MASW)

- Measures/characterizes seismic surface waves generated from various types of seismic sources—such as a sledgehammer



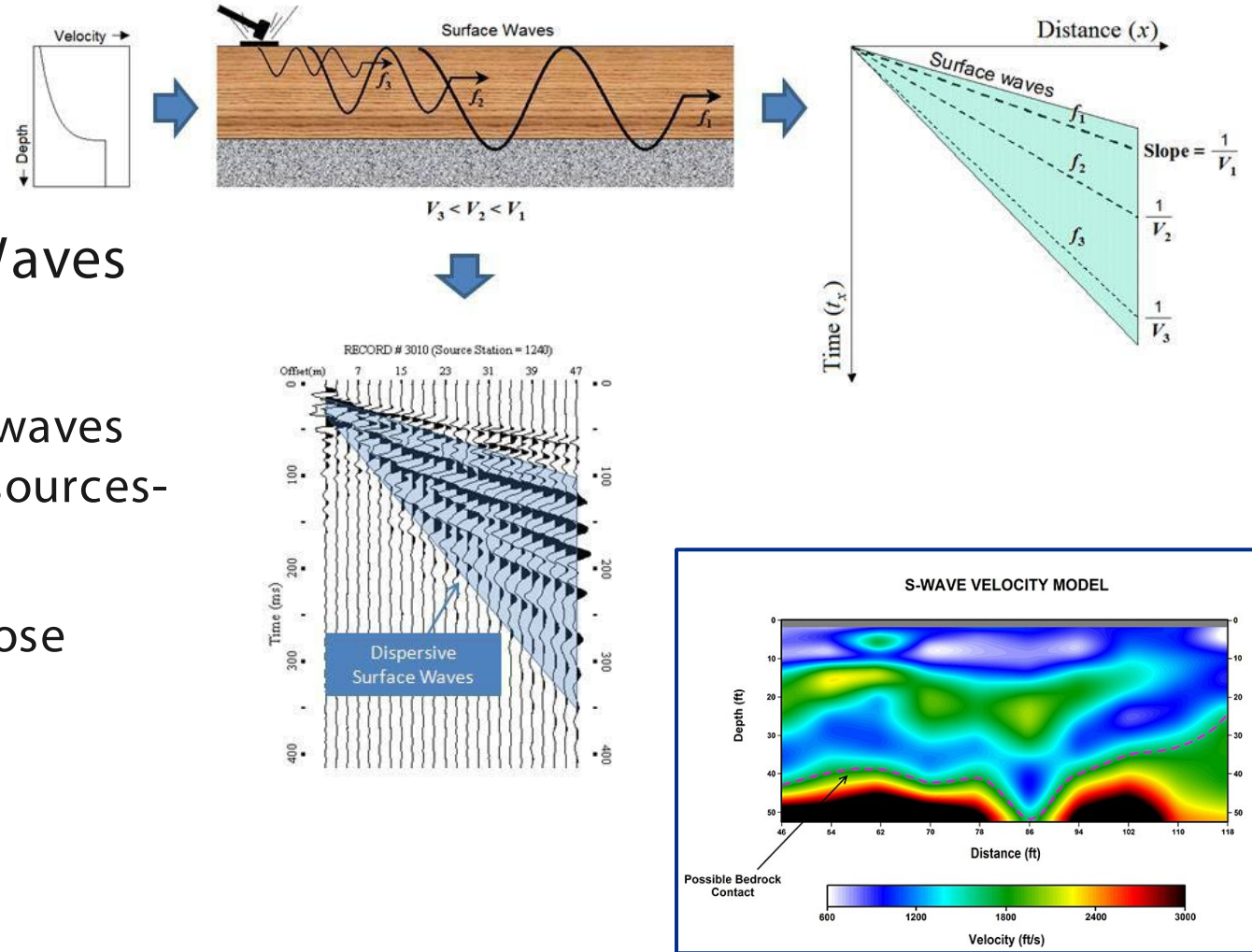
Source: <https://civiltectesting.com/geophysical-survey/multichannel-analysis-of-surface-waves/>



Geophysical Surveys

Multi-Channel Analysis of Surface Waves (MASW)

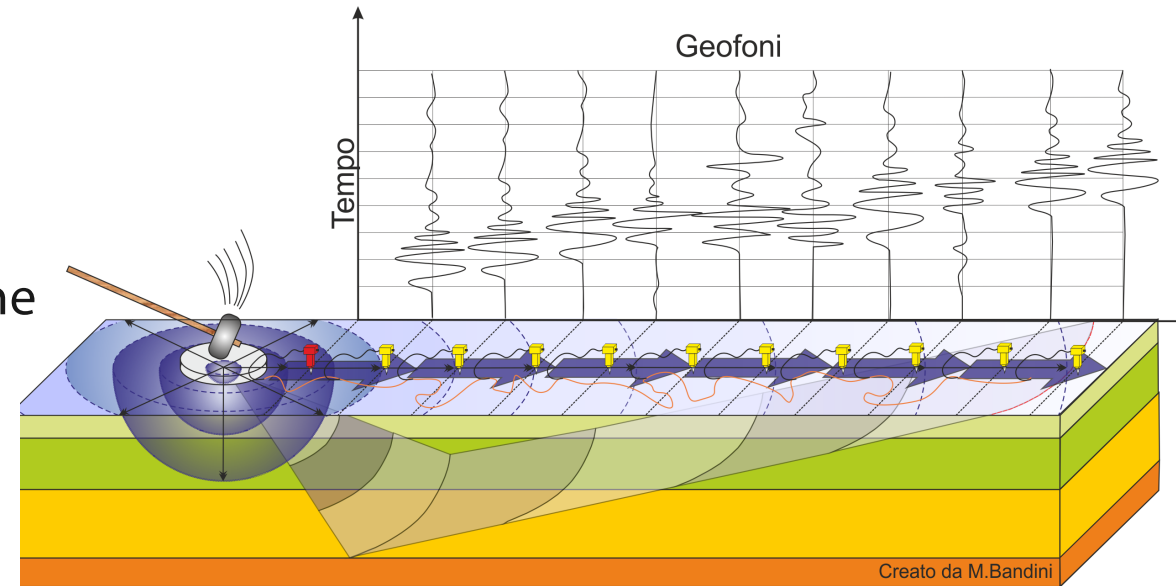
- Measures/characterizes seismic surface waves generated from various types of seismic sources- such as a sledge hammer
- Analyzes the propagation velocities of those surface waves



Geophysical Surveys

■ Multi-Channel Analysis of Surface Waves (MASW)

- Measures/characterizes seismic surface waves generated from various types of seismic sources- such as a sledge hammer
- Analyzes the propagation velocities of those surface waves
- Deduces shear-wave velocity variations below the surveyed area



Source: <https://help.geostru.eu/easymasw/es/introduzione.htm>

Geophysical Surveys

Multi-Channel Analysis of Surface Waves (MASW)

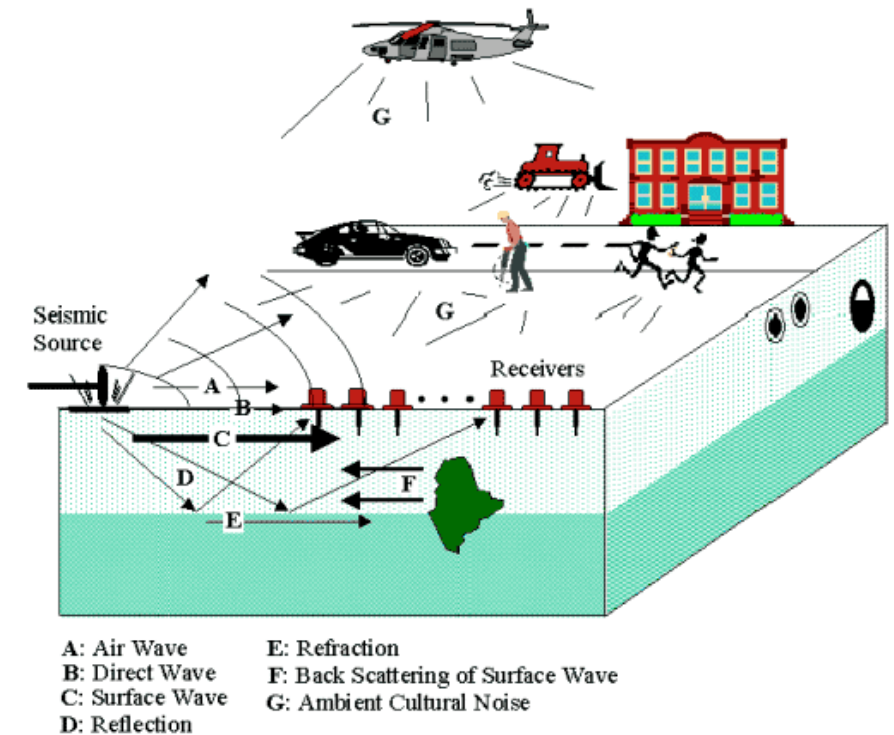
Benefits:

Effective in typical ambient noise

Sensitive to low velocity layers and velocity inversions

2-D and 3-D mapping capability

Measures V_s for site-specific seismic hazard analyses



Geophysical Surveys

— Multi-Channel Analysis of Surface Waves (MASW)

Benefits:

Effective in typical ambient noise

Sensitive to low velocity layers and velocity inversions

2-D and 3-D mapping capability

Measures V_s for site-specific seismic hazard analyses

Limitations:

Interpretation assumes a layered system with no lateral variation

Effective depth is limited by array lengths

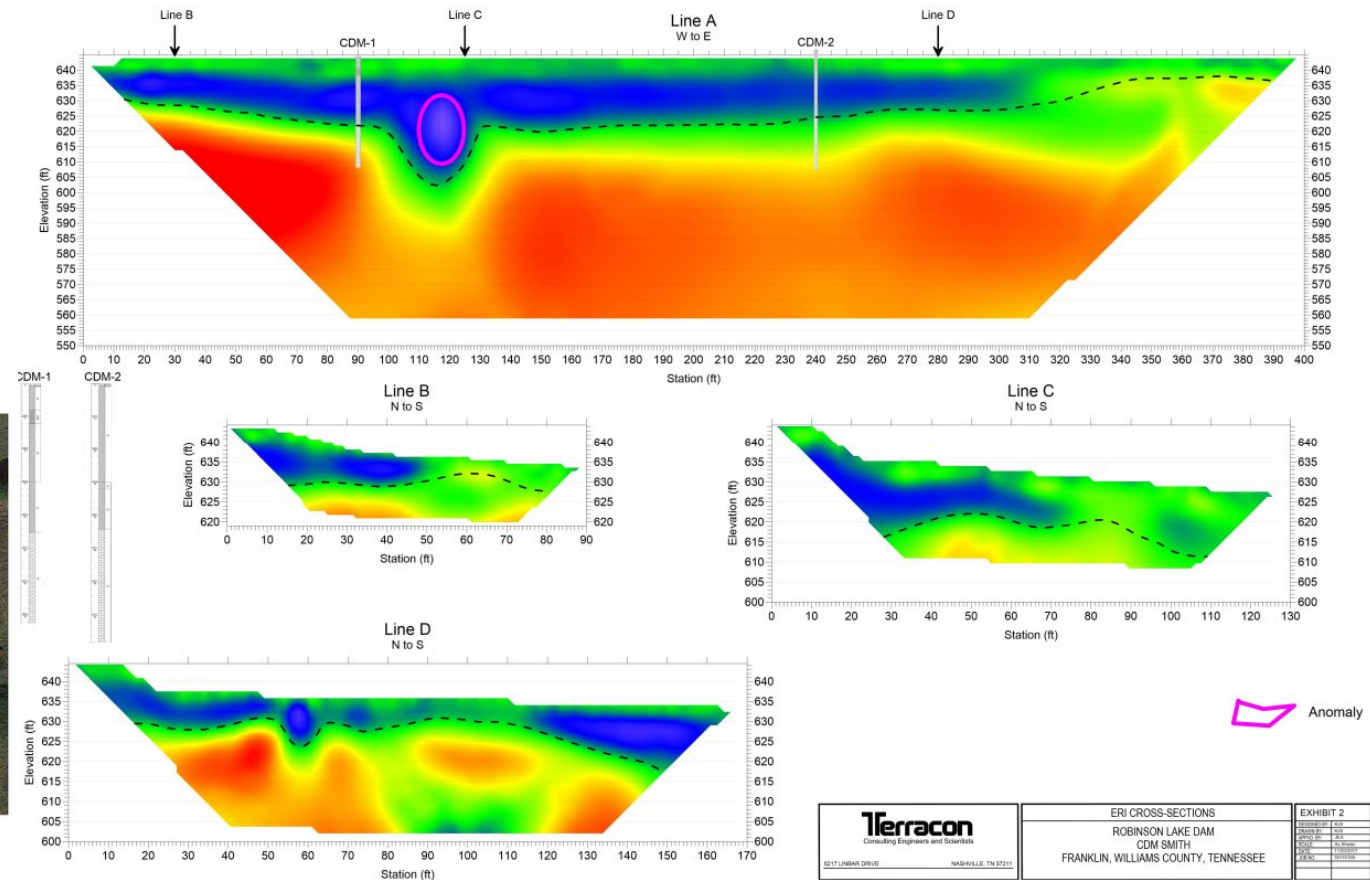
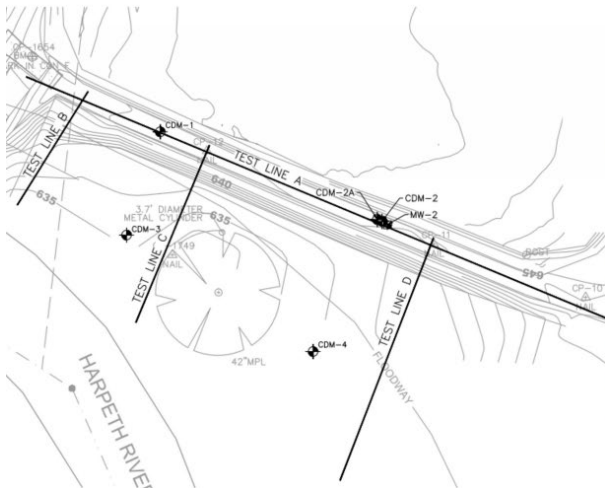
Thin layers or small anomalies can be missed

Inversion process is not always unique

Geophysical Surveys

■ Electrical Resistivity Tomography (ERT)

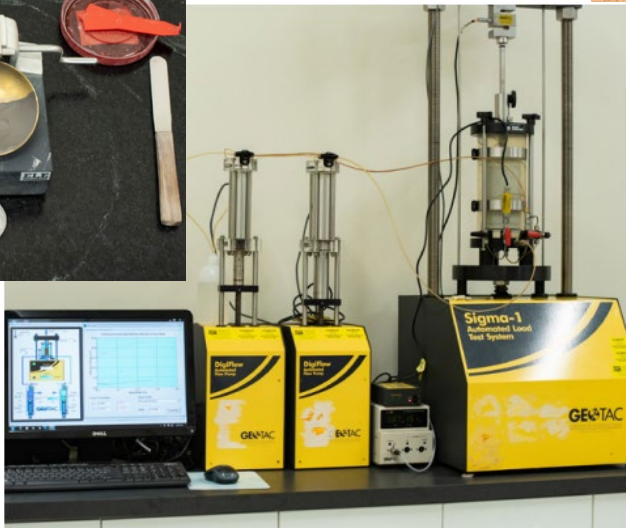
- Utilizes direct current to measure resistivity in the soil
- Strengths
 - Void Identification
 - Groundwater condition



Geotechnical Field Investigation

Subsurface Explorations:

- Penetration tests, pressure tests, in-situ strength tests, geophysical surveys, etc.
- Test pits, sample collection, and laboratory testing samples.



Source: <https://structville.com/geotechnical> -site-investigation

Geotechnical Field Investigation

■ Soil and Rock Drilling

- Solid Stem Continuous Flight Augers
- Hollow Stem Continuous Flight Augers
- Rotary Wash Borings
- Mud Rotary
- Air rotary boring
- Conventional or Wireline Core
- Bucket Auger Borings
- Hand Auger Borings

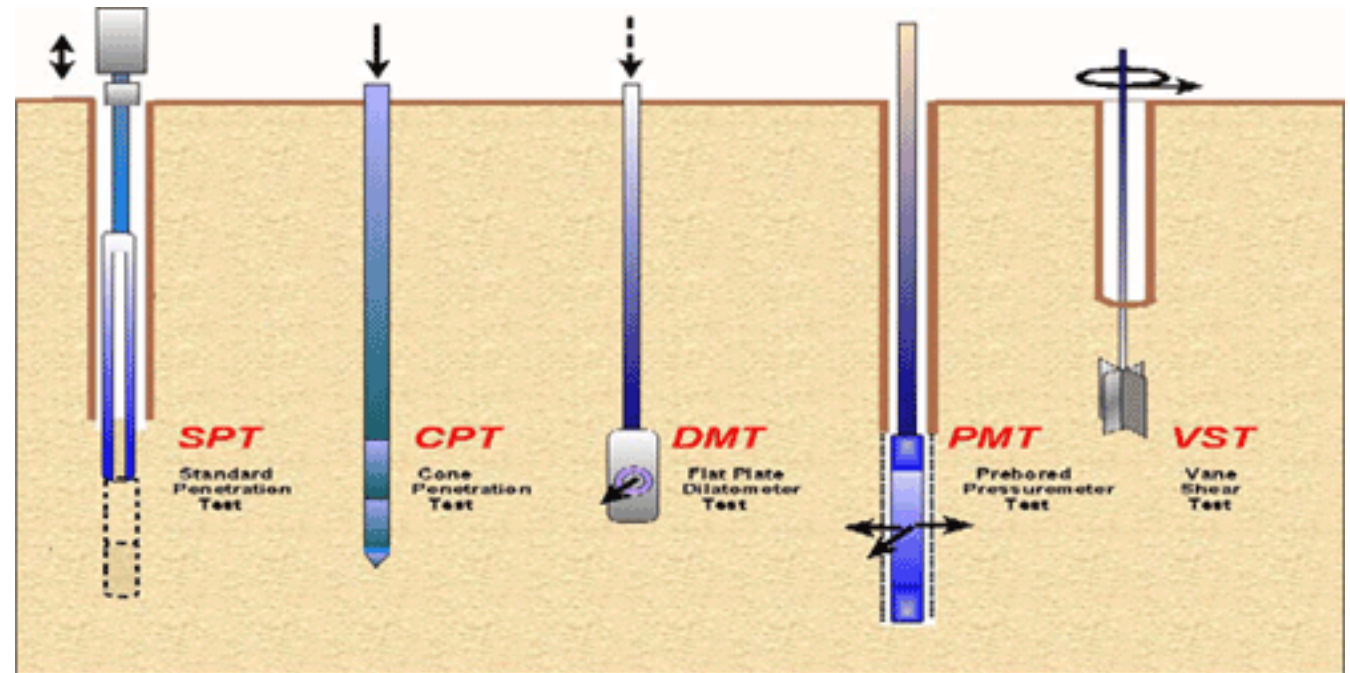


Source: <http://www.explorationcoredrilling.com/sale-12859873-hollow-stem-auger-8-1-4-210mm-triple-key-heavy-duty.html>

Geotechnical Field Investigation

■ In situ-testing:

- Standard Penetration Test (SPT)
- Cone Penetration Test (CPT)
- Flat Plate Dilatometer Test (DMT)
- Pressuremeter Test (PMT)
- Vane Shear Testing (VST)

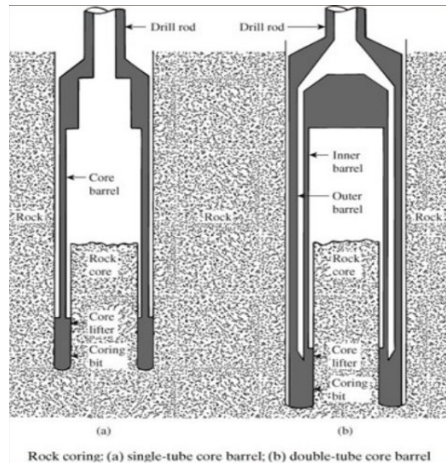


Source: <https://www.slideshare.net/slideshow/ensaios-laboratoriais-e-de-campo-eng-antonio-s-d-penna/>

Geotechnical Field Investigation

Standard sampling methods:

- Split Spoon
- Shelby Tube
- Rock Coring

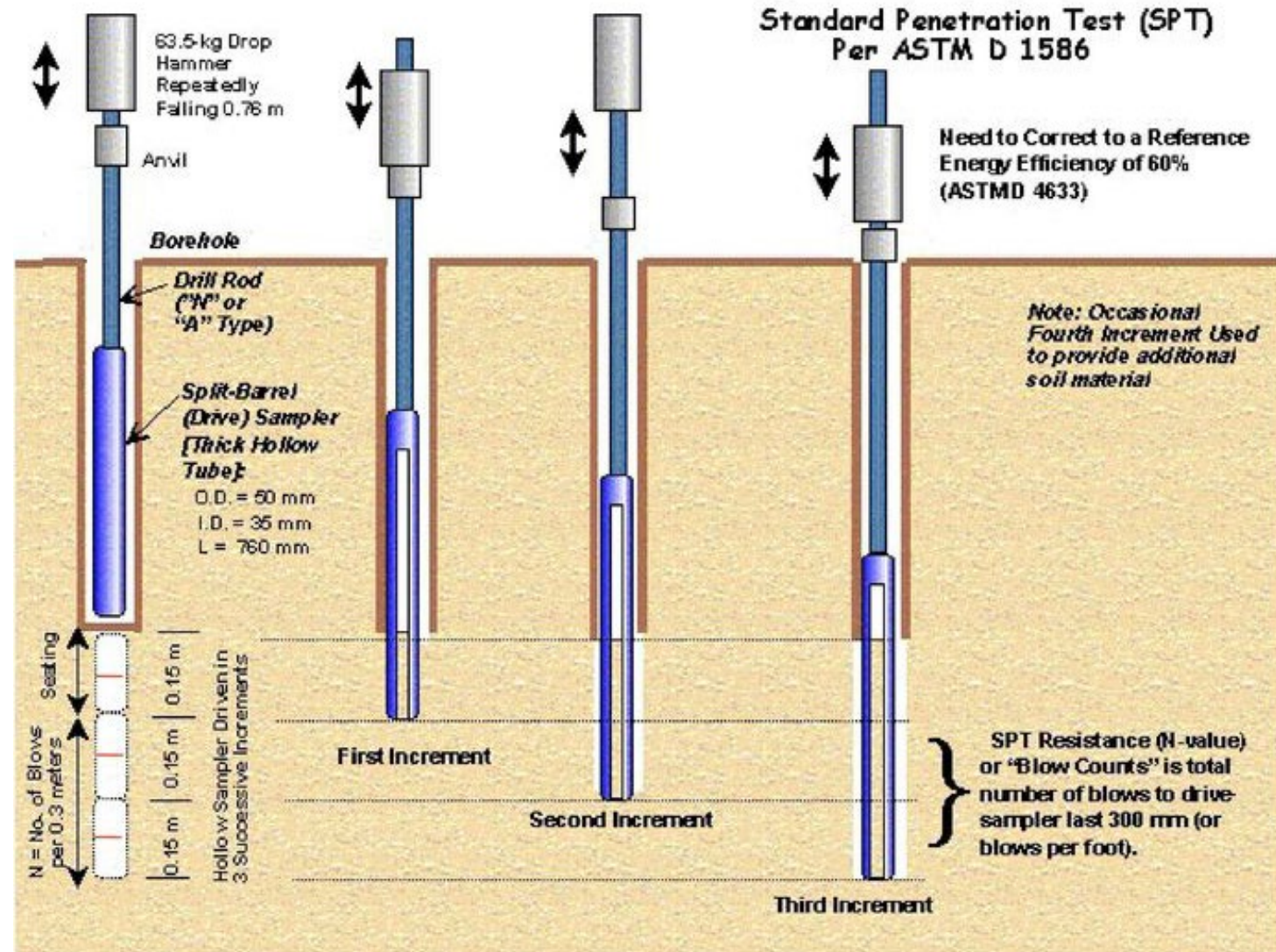


Source: <https://www.dynamicsgts.com.au/product/u63-and-u50-shelby-tube/>



Geotechnical Field Investigation

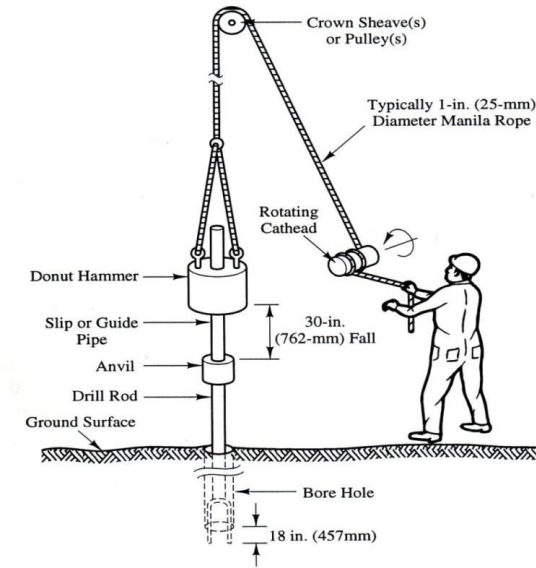
Standard Penetration Test (SPT)



Geotechnical Field Investigation

Standard Penetration Test (SPT)

- Performed at measurable depths during the advancement of a soil boring.
- Measures the dynamic soil resistance by driving a thick-walled tube into the ground.
- Collects a disturbed soil sample (split barrel type).



Geotechnical Field Investigation

Standard Penetration Test (SPT)

Benefits:

Obtain soil samples

Density/Consistency

Laboratory Testing

Accurate groundwater level reading

Penetrate through dense soil and rock

Simple and rugged

Suitable in many soil types

Available throughout the U.S.



Geotechnical Field Investigation

Standard Penetration Test (SPT)

<u>Benefits:</u>
Obtain soil samples
Density/Consistency
Laboratory Testing
Accurate groundwater level reading
Penetrate through dense soil and rock
Simple and rugged
Suitable in many soil types
Available throughout the U.S.

<u>Limitations:</u>
Testing can be slow (100 ft/day average)
Access and clearance limitations
Creates spoils and/or drilling fluid – Messy!
Disturbed samples (index test only)
Crude number for analyses (1 st order estimates)
Not suitable for very soft clays or silts
Not suitable for coarse gravel
High variability and uncertainty

Geotechnical Field Investigation

Shelby tube

- Collects “undisturbed” samples.
- Hydraulically pressed into the soil at the bottom of the borehole.
- Limited to soft soils.
- Maintains the soil structure.



Source: <https://fieldtech.tech/product/u63-and-u50-shelby-tube-sampler-for-thin-walled-soil-sampling/>



Source: <https://fieldtech.tech/product/u63-and-u50-shelby-tube-sampler-for-thin-walled-soil-sampling/>



Source: <https://www.flickrriver.com/photos/jsjgeology/53340311752/>

Geotechnical Field Investigation

Boring Logs

- Describe where, how deep, what equipment used, testing frequency and summaries.
- Classify the soil strata
 - Color
 - Moisture
 - Consistency/density
 - Type/Classification
 - Other descriptors

Crew: SCI		Rig: LME 550x (86%)		Drilling Method: Mud Rotary		Drilling Mud:			
Field Engineer: D.Schoen		Drill Rod Type & Diam:		Hours Drilling:		Hours Moving:			
SOIL STRATA				SAMPLING					
Stratum			Soil Description and Remarks	Sampled					
No.	From	To		From	To	1st 6"	2nd 6"	3rd 6"	N Value
①	0.5	2.5	FILL, slightly silty sand SP-SH/medium dense, moist, fine, greenish gray, few shell fragments, %200=, UC=, LL=, PI=	0.5	2	16	15	11	26
2	2.5	4.5	FILL, sandy clay, CH/stiff, moist, high plasticity, very dark gray	2.5	4	16	7	2	9
3	4.5	7	FILL, clay, CH/soft, moist, high plasticity, greenish gray	5	6.5	1	1	2	3
4	7	13.5	SAND, SP/loose, moist, fine, dark gray, few shell fragments	7.5	9	1	3	3	6
⑤	10		TUBE DESCRIPTION	10	12				
6	13.5	18	SANDY CLAY, CH/very soft, moist, high plasticity, dark gray	15	16.5	WOH	18"		WOH
⑦	18	48.5	CLAY, CH/very soft, moist, high plasticity, very dark gray, %200=, UC=, LL=, PI=	20	21.5	WOH	18"		WOH
⑧			...	25	27				
⑨	30		...%200=, UC=, LL=, PI=	30	31.5	WOH	18"		WOH
10			...	35	36.5	WOH	18"		WOH
⑪	40		...%200=, UC=, LL=, PI=	40	41.5	WOH	18"		WOH
⑫	45		...TUBE DESCRIPTION	45	47				
⑬	48.5	60	MARL, sandy silty, ML/stiff, moist, olive, Cooper Marl, %200=, UC=, LL=, PI=	50	51.5	3	5	7	12
14			...	55	56.5	2	3	6	9
⑮	60		%200=, UC=, LL=, PI=	60	61.5	2	5	6	11
16			...	65	66.5	3	5	5	10

NOTES: (Record boring offset, fluid losses, any unusual conditions & depths.)

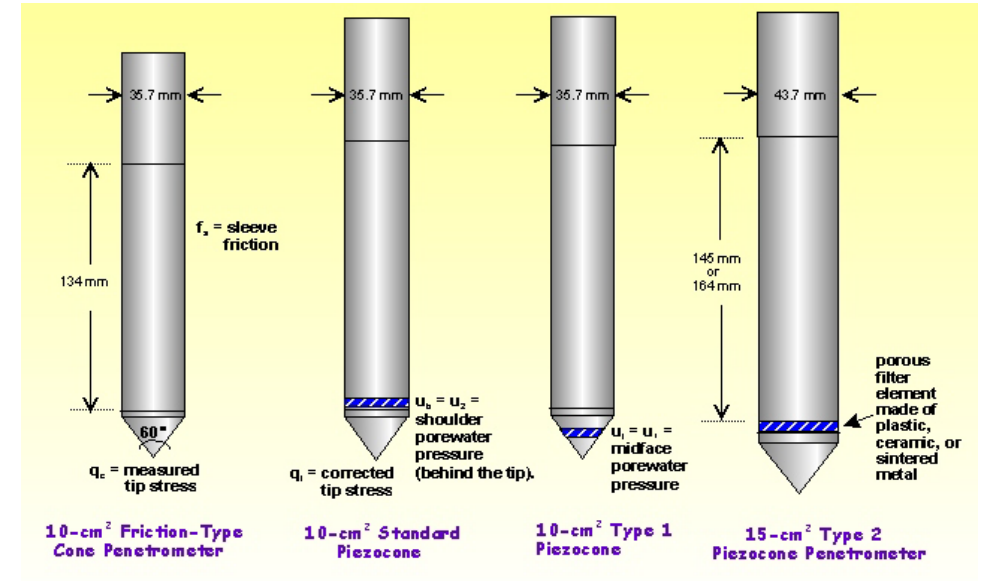
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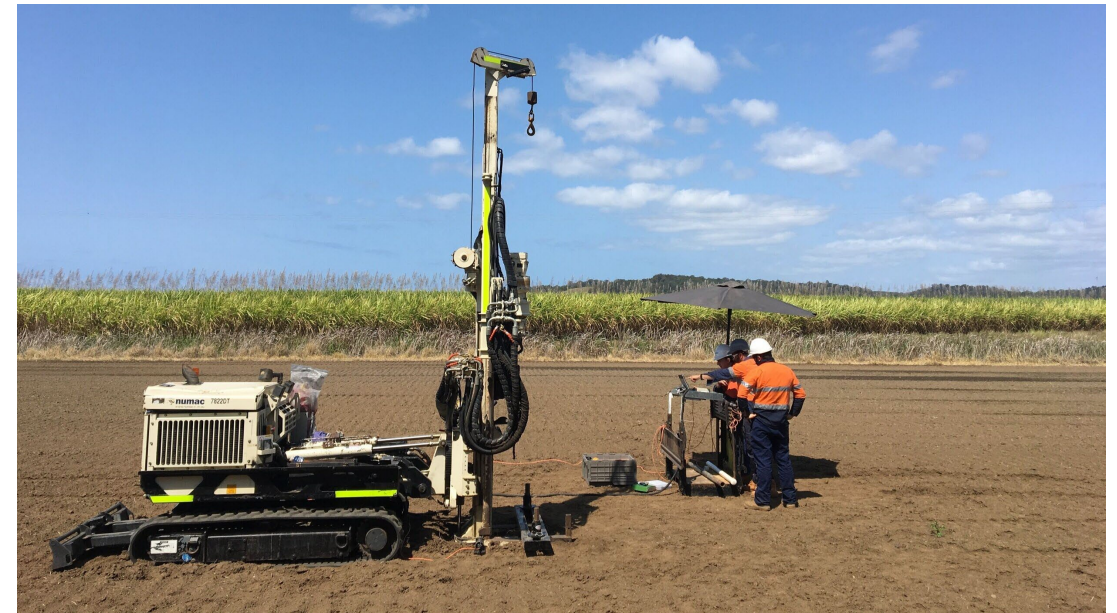
Geotechnical Field Investigation

Cone Penetration Test (CPT)

- Performed according to ASTM D3441 and D5778.
- Consists of pushing a cylindrical steel probe into the ground at a constant rate of 20 mm/s.



Source: <https://www.legiondrilling.com.au/cone-penetration-test-piezocone-cpt-cptu>



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- Penetration resistance is measured at the tip and along the shaft while inserting the probe.
- Some cones are fitted with a piezometric element to measure pore-pressure fluctuations (CPTU).

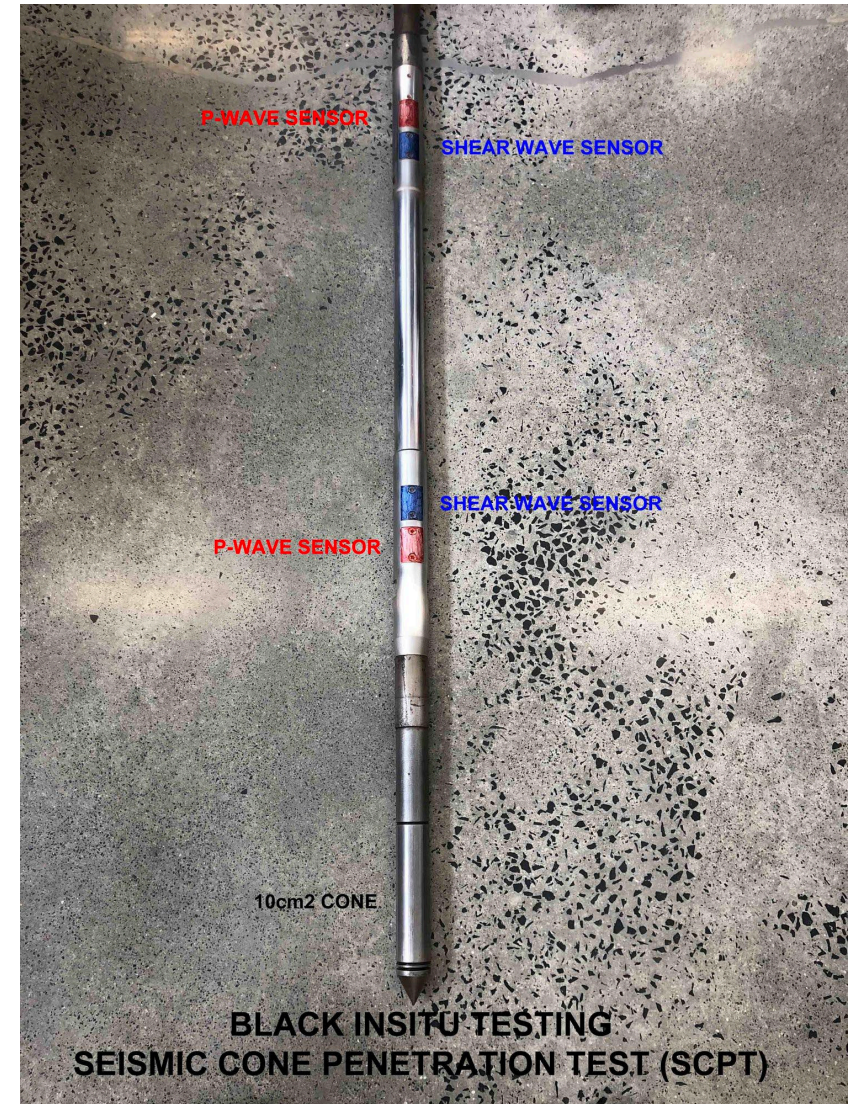


Source: <https://www.legiondrilling.com.au/cone> -penetration-test-plezocone-cpt-cptu

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- Penetration resistance is measured at the tip and along the shaft while inserting the probe.
- Some cones are fitted with a piezometric element to measure pore-pressure fluctuations (CPTU).
- Some cones are equipped with geophones to measure the small-strain modulus for seismic analyses (SCPT/SCPTU).



Source: Adapted from <https://www.blackinsitutesting.com.au/seismic-cone-penetration-test>

Geotechnical Field Investigation

Cone Penetration Test (CPT)

Benefits:

Cost: Inexpensive (Usually per day)

Rapid testing (average 400 ft/day)

Continuous data collection

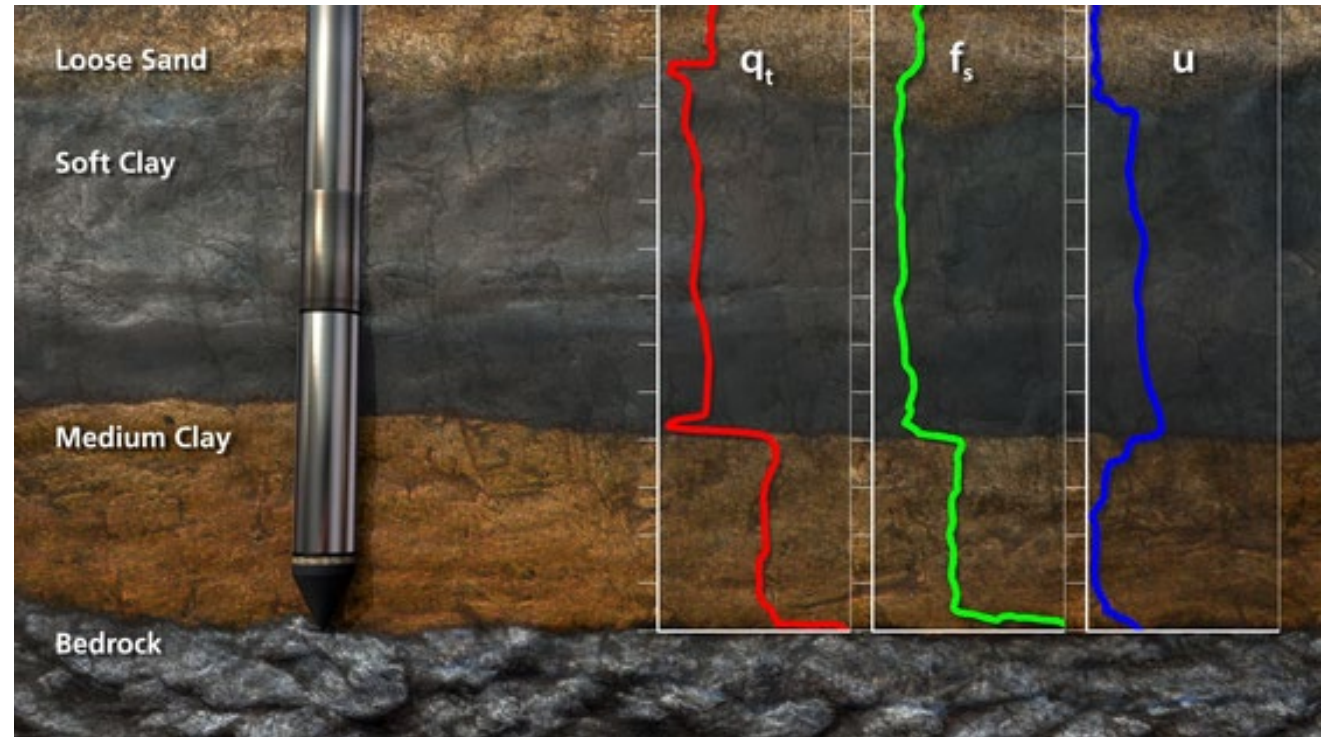
Tip and friction resistance measurements

Measures pore pressure directly

Strong theoretical basis in interpretation

Results not operator – dependent

Develop shear wave velocity (V_s) profile (with SCPT) to support seismic analyses



Source: <https://content.govdelivery.com/accounts/USDOTFHWA/bulletins/>

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Develop shear wave velocity (V_s) profile (with SCPT) to support seismic analyses

Limitations:

No soil samples

No laboratory testing

Requires a skilled operator to run

Electronic drift, noise, and calibration

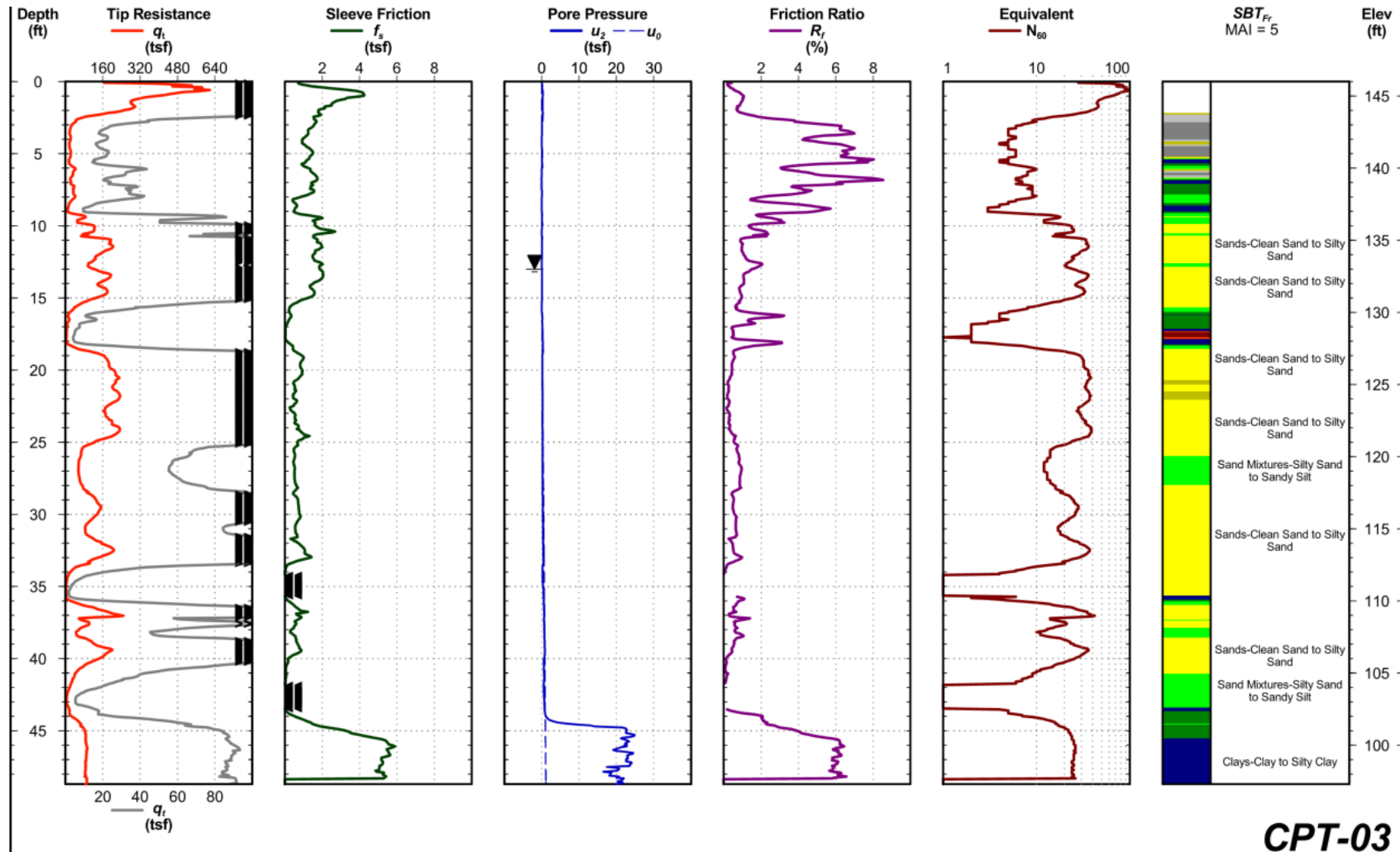
Not suitable for dense soil deposits

Not suitable for gravel soil

Must interpret phreatic groundwater conditions

Geotechnical Field Investigation

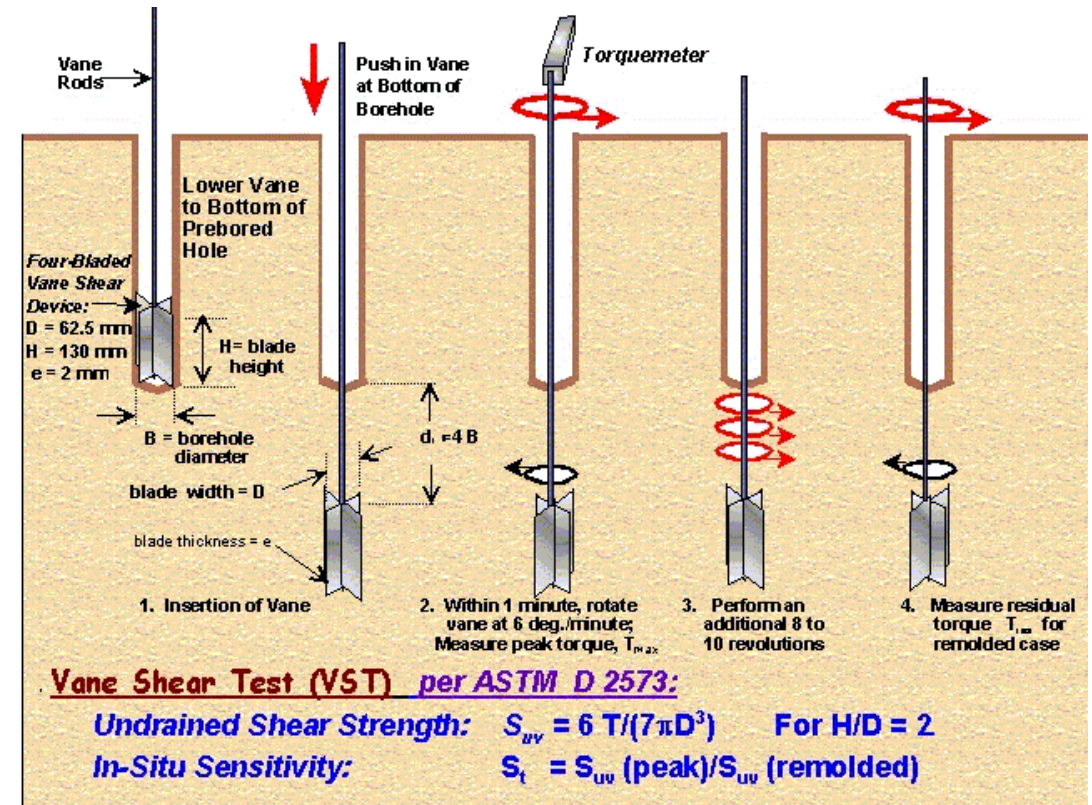
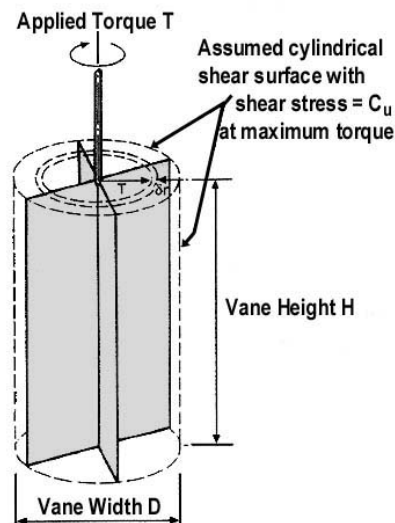
CPT Sounding Logs



Geotechnical Field Investigation

Vane Shear Testing (VST)

- Consists of inserting a four-bladed vane into the soil and rotating the device about a vertical axis.
- Evaluates in-place undrained shear strength.
- Applicable for soft to stiff clays and silts.
- Typically, performed at 1-meter intervals.



Geotechnical Field Investigation

■ Vane Shear Testing (VST)

Benefits:

Direct measure of undrained shear strength

Simple test and equipment

Measure in-situ clay sensitivity

Strong theoretical basis in interpretation

Long history of use in practice



Source: <https://servicesupplyamerica.com/products/field-vane-shear-tester>

Geotechnical Field Investigation

— Vane Shear Testing (VST)

Benefits:

Direct measure of undrained shear strength

Simple test and equipment

Measure in-situ clay sensitivity

Strong theoretical basis in interpretation

Long history of use in practice

Limitations:

Only suitable for soft to stiff fine-grained soil

Slow and time consuming

Raw shear strength needs (empirical) correction

Can be affected by sand lenses and seams

Structural Field Testing

■ Hammer Sounding

- Simple, non-destructive test
- Consists of determining the integrity of concrete structures by using sound quality
- Detects delamination, voids, or honeycombing



Source: <https://guideofgreece.com>



Source: <https://soundingtech.com>

Structural Field Testing

— Hammer Sounding

Benefits:

Identify delamination in concrete

Non-destructive testing

Visual inspection to determine concrete condition

Horizontal and vertical surfaces

Can also be used on metal fastener and timber members

Minimal training required

Inexpensive



Source: <https://wisconsin.dot.gov/dtsdManuals/struct/inspection/Insp-fm-pt5ch3.pdf>

Structural Field Testing

— Hammer Sounding

Benefits:

Identify delamination in concrete

Non-destructive testing

Visual inspection to determine concrete condition

Horizontal and vertical surfaces

Can also be used on metal fastener and timber members

Minimal training required

Inexpensive

Limitations:

Physically demanding and time consuming

Data recording must be done manually using field sketches and photographs

Results subjective and depend on the experience of the inspector

May not detect early-stage or deep delamination

Can be affected by environmental noise

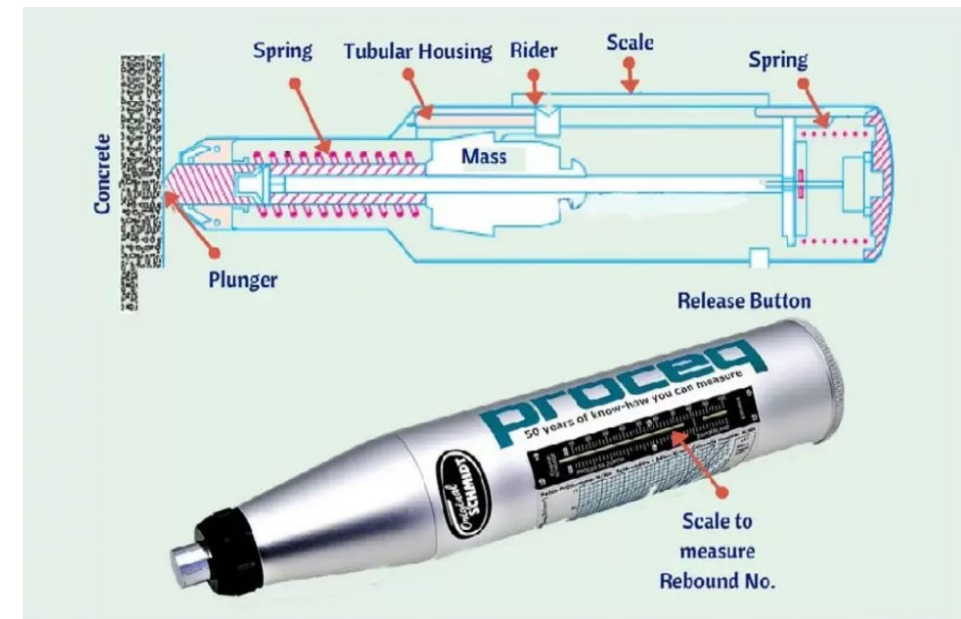
Structural Field Testing

Rebound Hammer

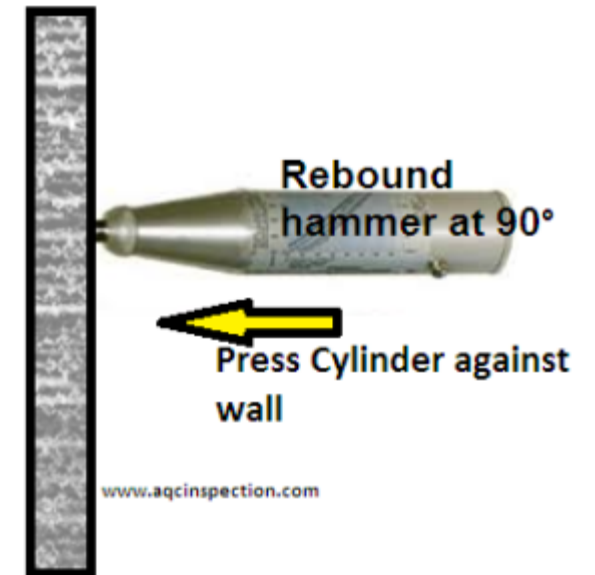
- Simple, easy, non-destructive test
- Determine the surface hardness of concrete
- Detects weak spots or areas of poor quality
- Higher rebound -> harder surface -> higher estimated strength
- Commonly referenced in ASTM C805



Source: <https://housing.com/news/rebound-hammer-test/>



Source: <https://www.onestopndt.com/ndt-articles/rebound-hammer-test-concrete>



Structural Field Testing

Rebound Hammer

Benefits:

Identify surface hardness of concrete

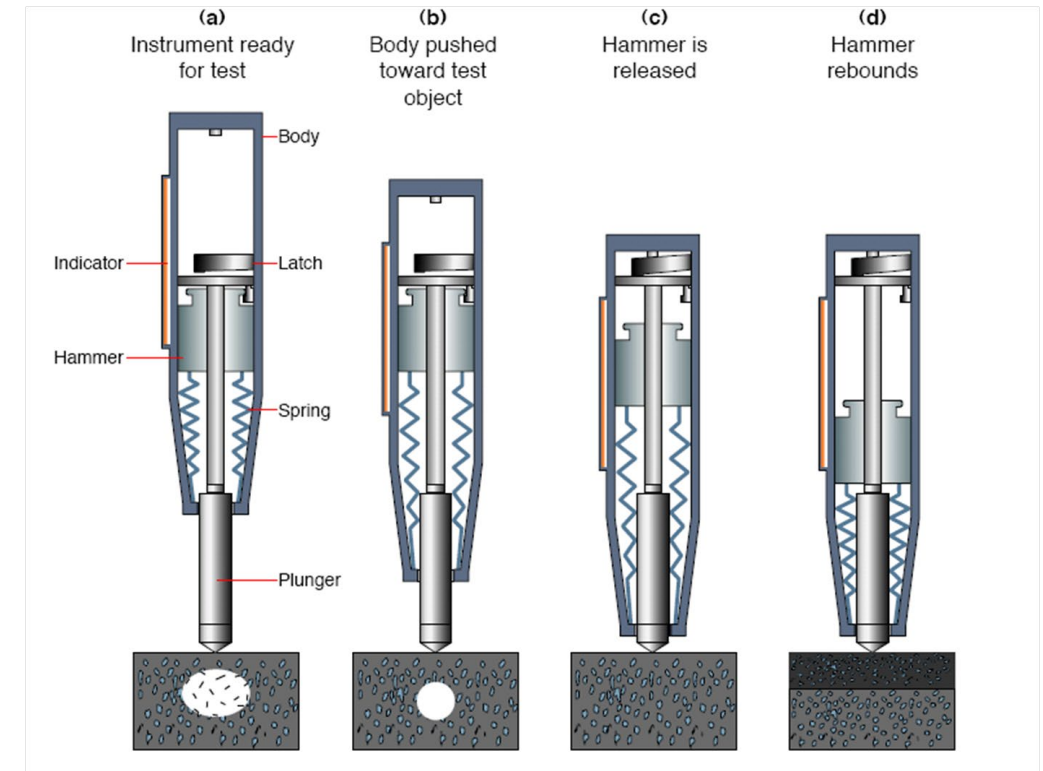
Non-destructive testing

Horizontal and vertical surfaces

Simple and easy to use

Portable and inexpensive

Various types of concrete surfaces – Fresh and hardened concrete



Structural Field Testing

Rebound Hammer

Benefits:

Identify surface hardness of concrete

Non-destructive testing

Horizontal and vertical surfaces

Simple and easy to use

Portable and inexpensive

Various types of concrete surfaces – Fresh and hardened concrete

Limitations:

Test accuracy is limited

It does not measure compressive strength

Could be affected by surface conditions such as moisture, carbonation, and/or aggregate type

Not for high strength concrete (beyond 60 to 70 MPa)

Required calibration curves

Structural Field Testing

■ Ultrasonic Pulse Velocity (UPV) Testing

- Evaluates the quality, uniformity, and integrity of concrete
- Detects cracks, voids, and internal flaws
- Quick, non-destructive test
- Estimates modulus of elasticity and can be correlated with compressive strength
- Commonly referenced in ASTM C597



Source: <https://geotechpedia.com/Equipment/Show/731/Ultrasonic-pulse-velocity-testers>



Source: <https://sipilab.blogspot.com/2013/11/concrete-testing-by-ultrasonic-pulse.html>

Structural Field Testing

— Ultrasonic Pulse Velocity (UPV) Testing

Benefits:

Identify homogeneity of concrete

Quick, non-destructive testing

Detects internal concrete defects such as cracks and voids

Portable testing apparatus

Estimate modulus of elasticity and can be correlated with compressive strength

Quality control during construction



Source: <https://www.tcreng.com/post/ultrasonic-pulse-velocity-upv-testing-enhancing-civil-infrastructure-assessment>

Structural Field Testing

— Ultrasonic Pulse Velocity (UPV) Testing

Benefits:

Identify homogeneity of concrete

Quick, non-destructive testing

Detects internal concrete defects such as cracks and voids

Portable testing apparatus

Estimate modulus of elasticity and can be correlated with compressive strength

Quality control during construction

Limitations:

Requires experienced technicians

Requires good surface contact (access to opposite faces for direct transmission)

Could be affected by environmental conditions such as temperature and humidity

Could be affected by surface conditions such as moisture and aggregate type

May not be able to detect cracks in low-quality or thin concrete structures

Structural Field Testing

Concrete Coring

- Destructive testing method
- Extracting cylindrical samples (cores) for laboratory analysis
- Determines compressive strength of in-place concrete
- Assess density, permeability and quality of concrete
- Assess structural integrity of existing structures
- Commonly referenced in ASTM C42



Source: <https://wecutsl.com/photos/concrete-coring-photos/>



Source: <https://concreteinsight.com/concrete-coring/>

Structural Field Testing

Concrete Coring

Benefits:

Compressive strength of in-place concrete

Internal condition of concrete

Quality control in construction

Samples tested for density, permeability and quality of concrete

Assess structural integrity of structures



Source: <https://www.concrete-cutting-perth.com.au>

Structural Field Testing

Concrete Coring

Benefits:

Compressive strength of in-place concrete

Internal condition of concrete

Quality control in construction

Samples tested for density, permeability and quality of concrete

Assess structural integrity of structures

Limitations:

Destructive testing – leaves holes in structures

Requires repairs after coring

Time consuming and expensive

Potential for damage to the structure

Requires specialized equipment

Geotechnical and Structural Field Investigation

— Potential Complications:

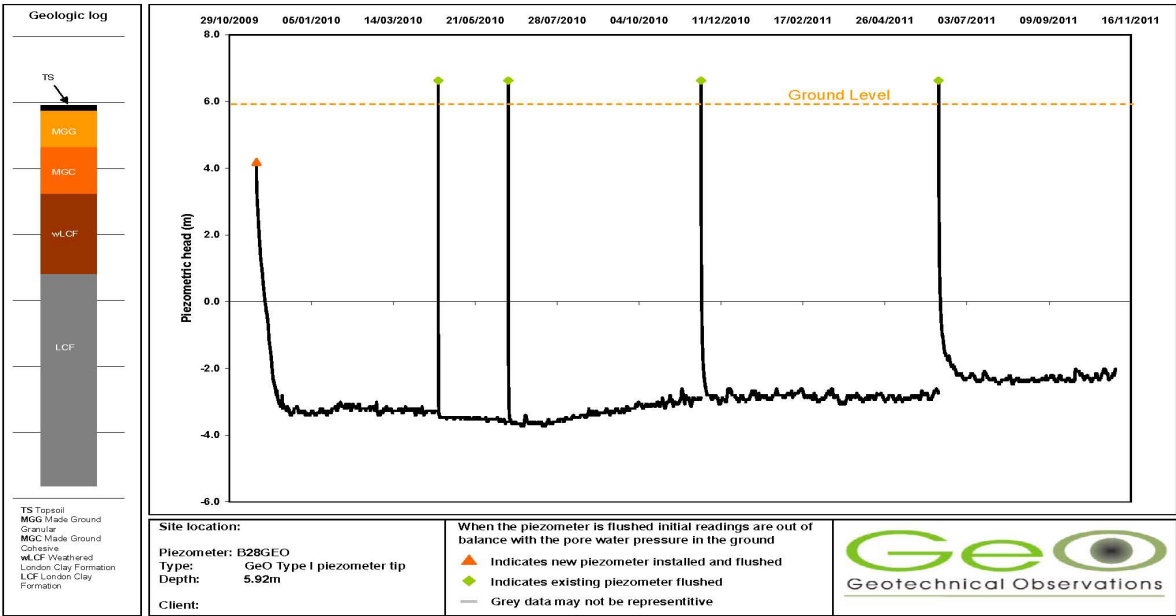
- Utilities
- Site access
 - Soft grounds
 - Mountainous
 - Within waterways
 - Divers or gate control requirements to lower reservoir
 - On or within Structures
 - Rope and pulley access or drone inspections
 - Within roadways
- Weather
 - Driller schedules
 - Lab testing schedules
 - Client / Project Schedule



Instrumentation Installation and Monitoring

Instrumentation and Monitoring

- Piezometers (vibrating wire, strain gauge, Fiber optic, etc)



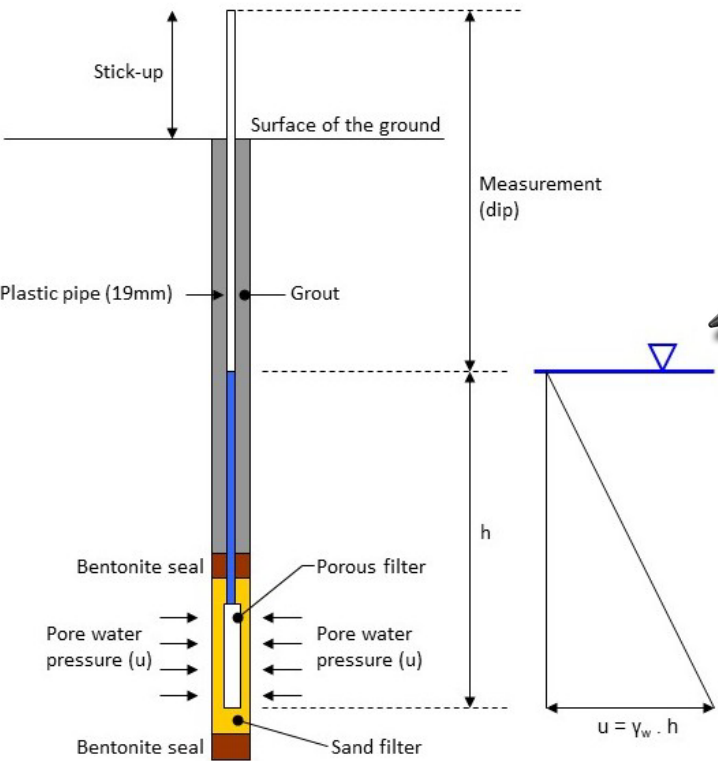
Source: <https://www.geo-observations.com/piezometers>



Source: <https://www.legiondrilling.com.au/drilling-stories/vibrating-wire-piezometers-accurate-and-reliable-groundwater-monitoring>



Source: <https://www.geosense.com/products/strain-gauge-piezometer/>



Source: <https://www.geo-observations.com/piezometers>



Source: <https://www.soilinstruments.com/products/optical-fiber-sensors/fop-piezometer/>

Instrumentation Installation and Monitoring

Instrumentation and Monitoring

- Piezometers (vibrating wire, strain gauge, Fiber optic, etc)
- Inclinerometers



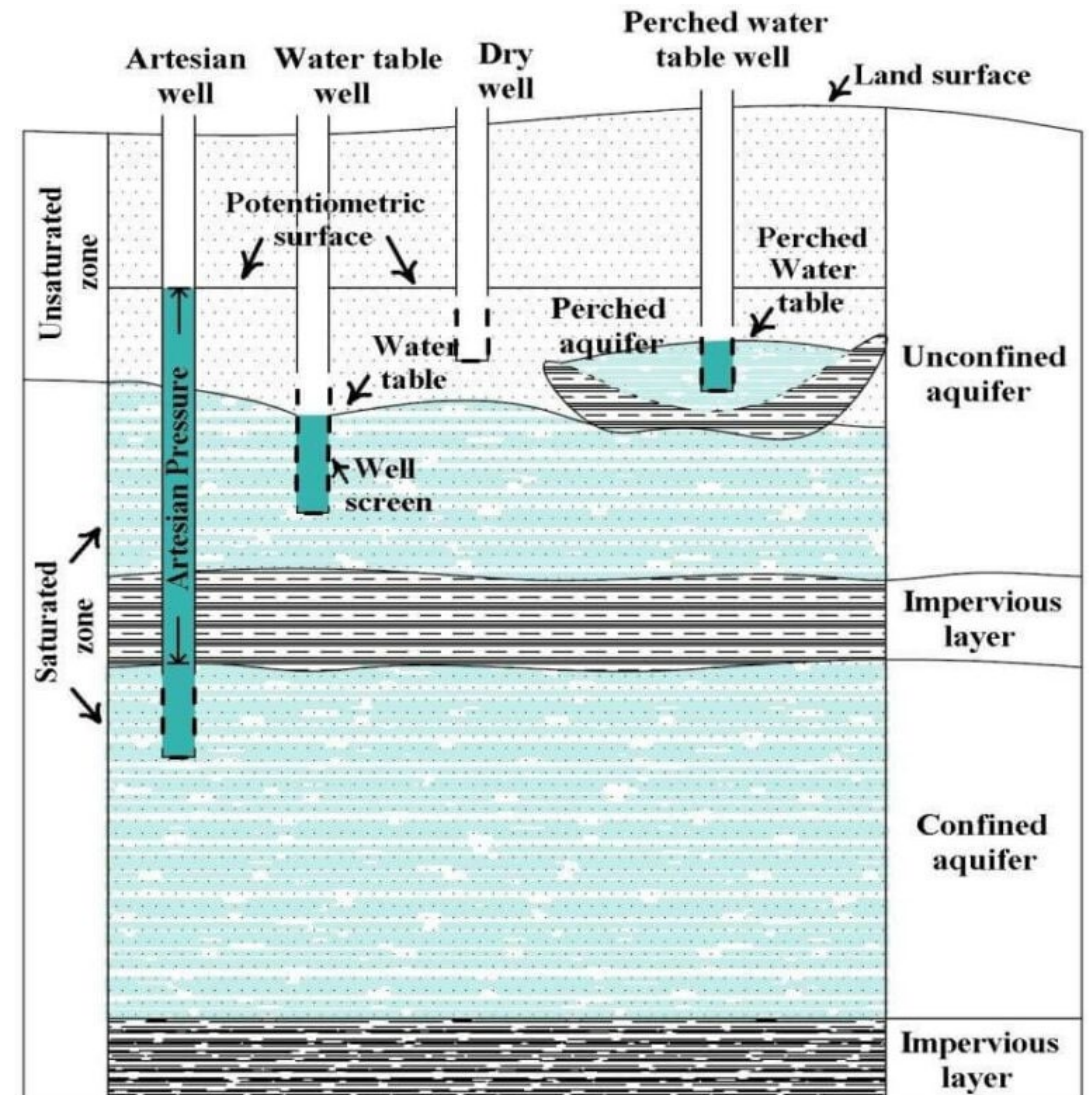
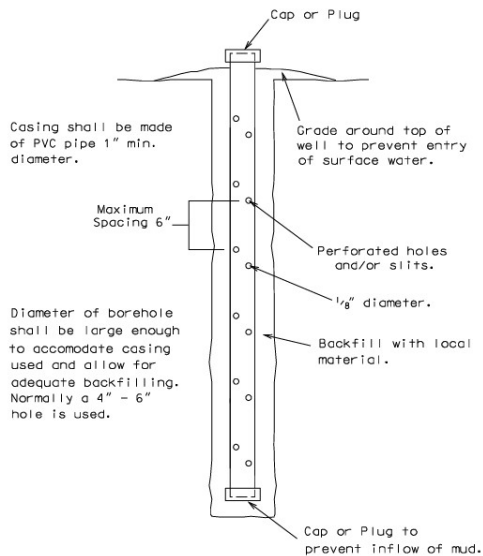
Source: <https://www.douglaspartners.com.au/knowledge-sharing/how-inclinometers-assist-geotechnical-monitoring>

Instrumentation Installation and Monitoring

Instrumentation and Monitoring

- Piezometers (vibrating wire, strain gauge, Fiber optic, etc)
- Inclinometers
- Observation wells

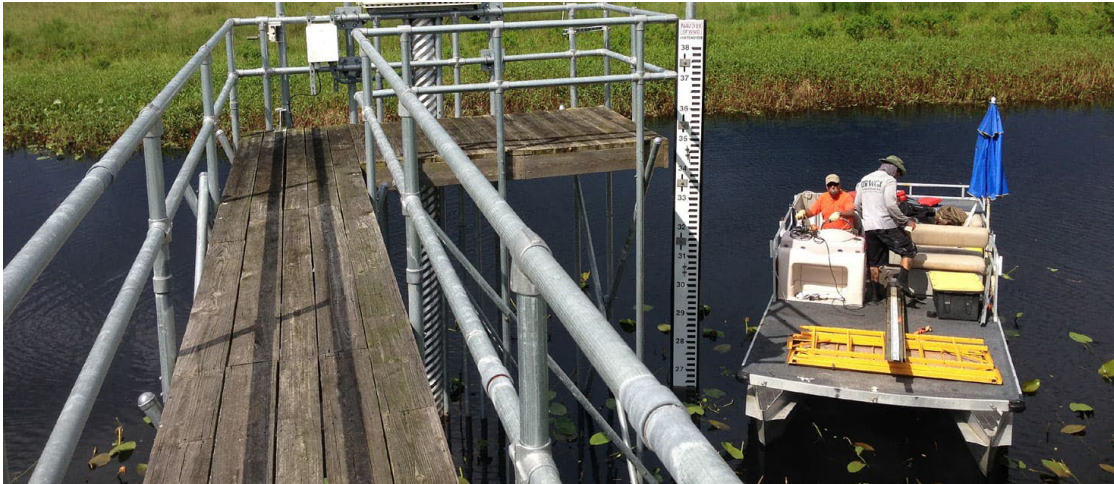
CASED OBSERVATION WELL



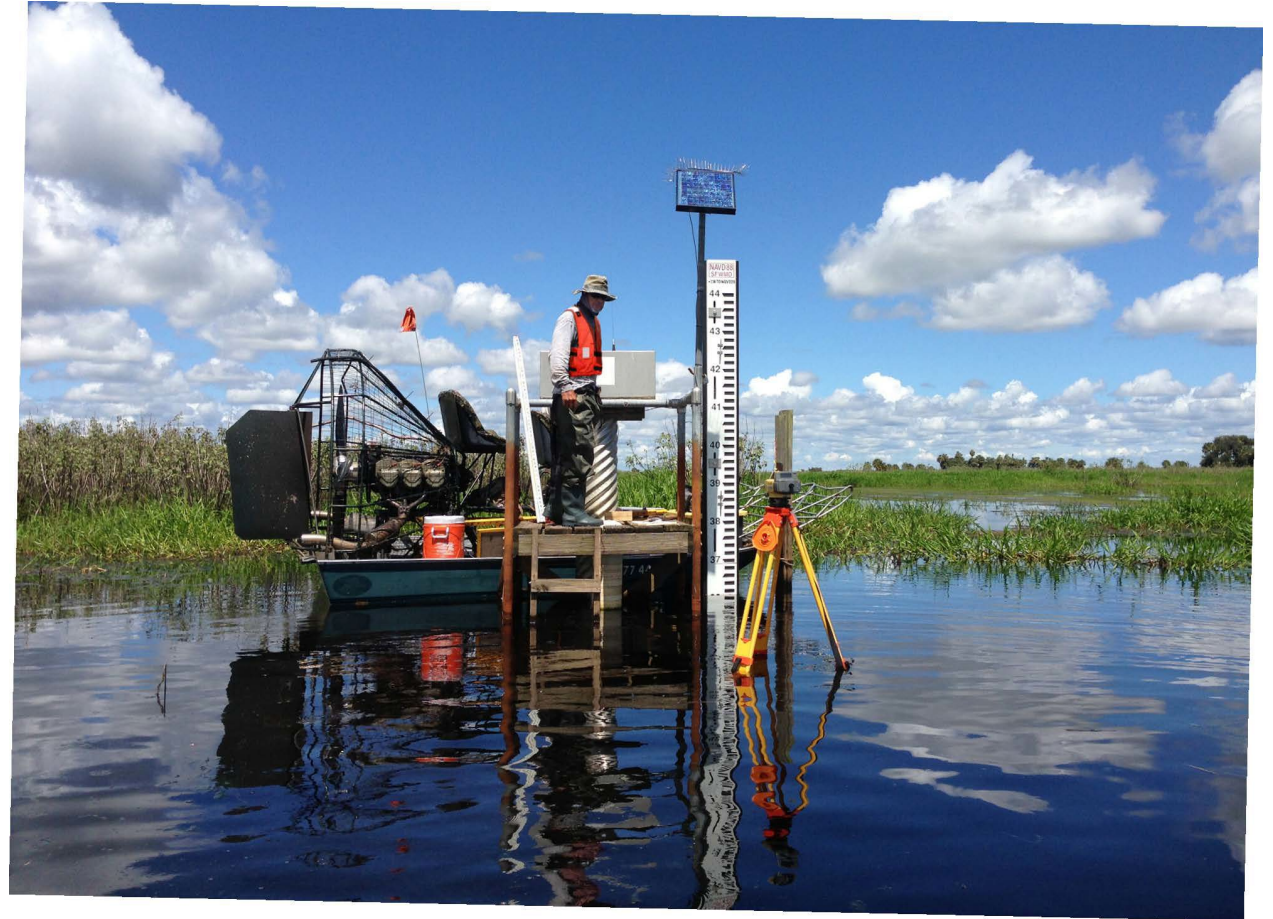
Source: <https://preparednessadvice.com/cost-to-dig-a-well/>

Instrumentation Installation and Monitoring

- Instrumentation and Monitoring
 - Piezometers (standpipe, vibrating wire)
 - Inclinometers
 - Observation wells
 - Staff gauges and recorders



Source: <https://wginc.com/projects/sfwmd> -hydrology-and-hydraulics -staff-gauges/

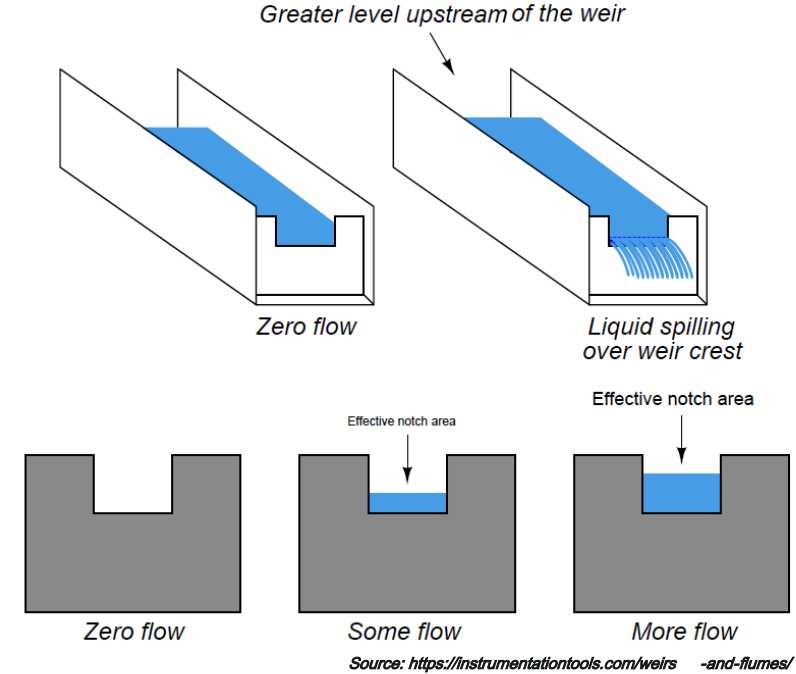


Source: <https://wginc.com/projects/sfwmd> -hydrology-and-hydraulics -staff-gauges/

Instrumentation Installation and Monitoring

Instrumentation and Monitoring

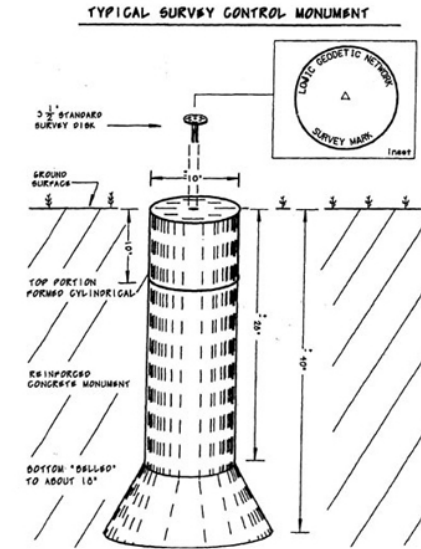
- Piezometers (standpipe, vibrating wire)
- Inclinometers
- Observation wells
- Staff gauge and recorders
- Weirs and flumes for volume measurement



Instrumentation Installation and Monitoring

Instrumentation and Monitoring

- Piezometers (standpipe, vibrating wire)
- Inclinometers
- Observation wells
- Staff gauge and recorders
- Weirs and flumes for volume measurement
- Survey monuments for deformation monitoring



Source: <https://rfa.sc.gov/programs-services/geodetic/heightmodernization>

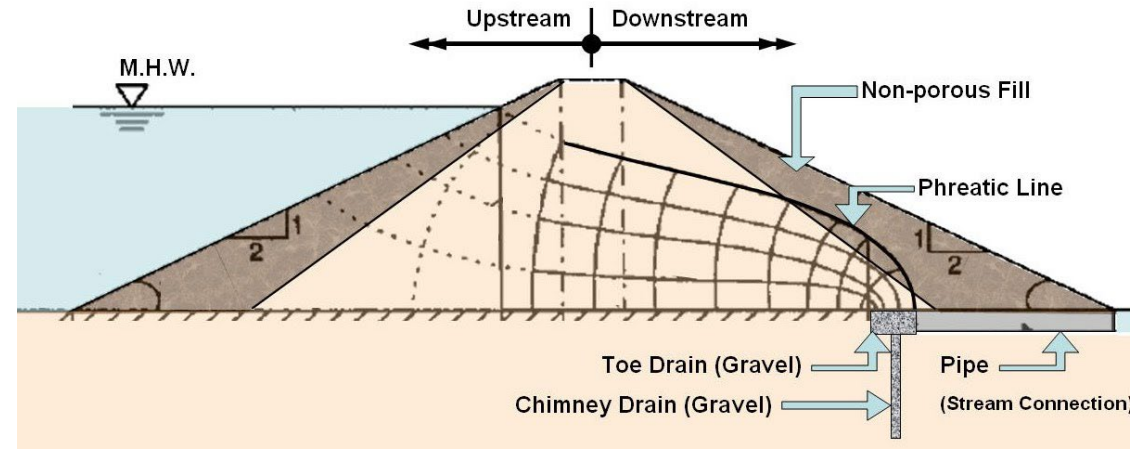


Source: <https://www.inltd.ca/services/general/high-precision-deformation-monitoring-surveys/>

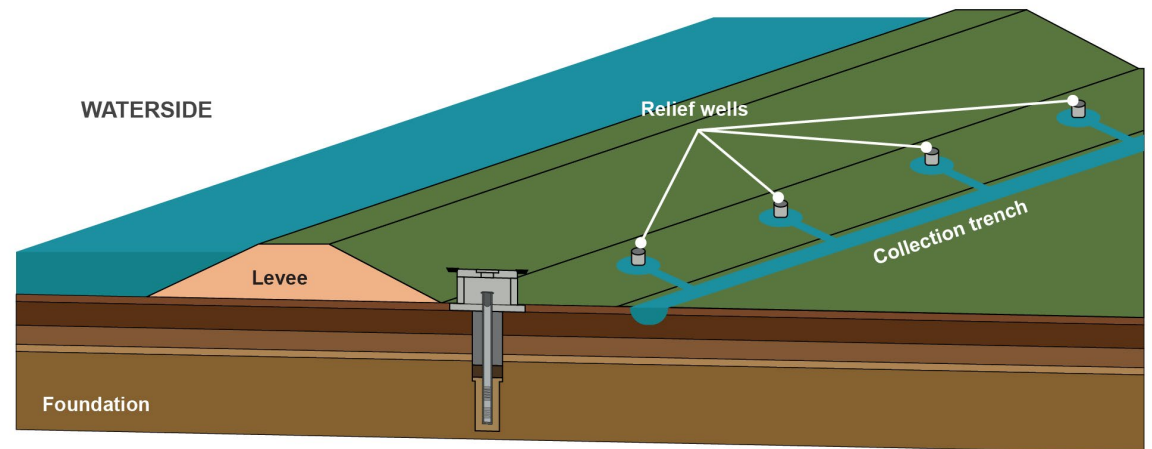
Instrumentation Installation and Monitoring

Instrumentation and Monitoring

- Piezometers (standpipe, vibrating wire)
- Inclinometers
- Observation wells
- Staff gauge and recorders
- Weirs and flumes for volume measurement
- Survey monuments for deformation monitoring
- Drainage system inspection (toe drains, relief wells)



Source: <https://www.primagem.org/toe-drain/>



Source: https://www.usace.army.mil/Missions/Civil-Works/Draft_LSP/



Instrumentation Installation and Monitoring

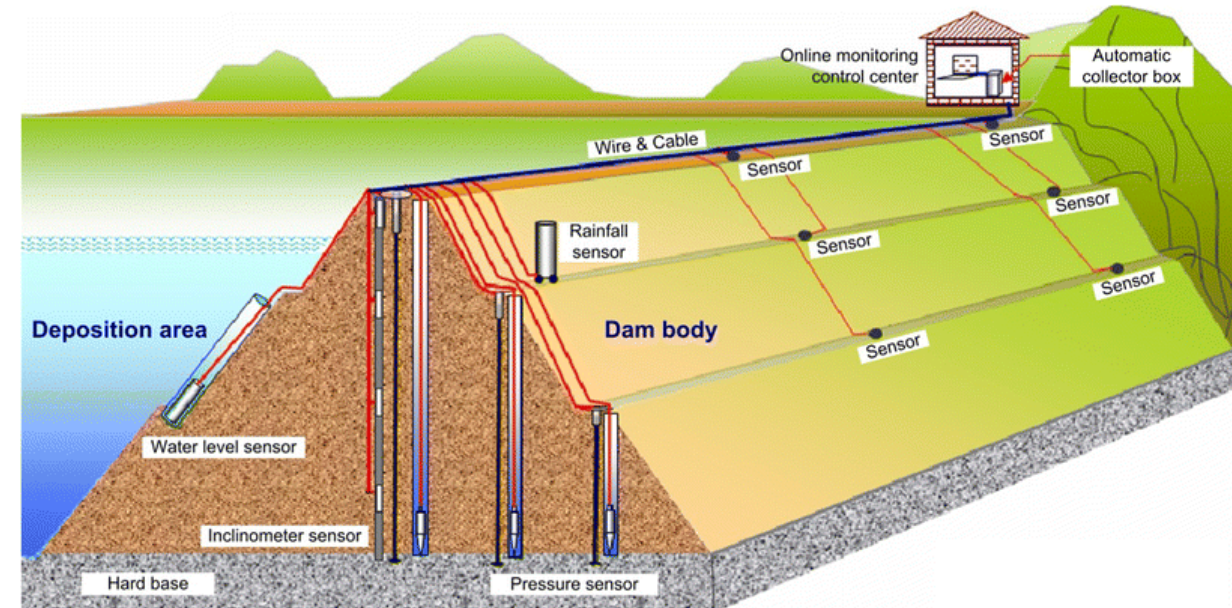
— Instrumentation Plan Design Strategy

1. Review historical/existing instrumentation data.
2. Determine potential data gaps or anomalies.
3. Install supplementary instrumentation to fill data gaps or complement existing instrumentation near anomalies.
4. Determine monitoring schedule for existing and new instrumentation.
5. Outline threshold values or data trends that would trigger more detailed evaluations.

Instrumentation Installation and Monitoring

Monitoring Schedule - Project Specific Approach

- Routine monitoring
 - Dam is under normal operation conditions (stable behavior)
- Enhanced Monitoring
 - Elevated dam reservoir levels
 - Extreme weather events
 - Unusual loading conditions
- Continuous Monitoring
 - Signs of distress or potential failure
 - Abnormal seepage, rapid deformation

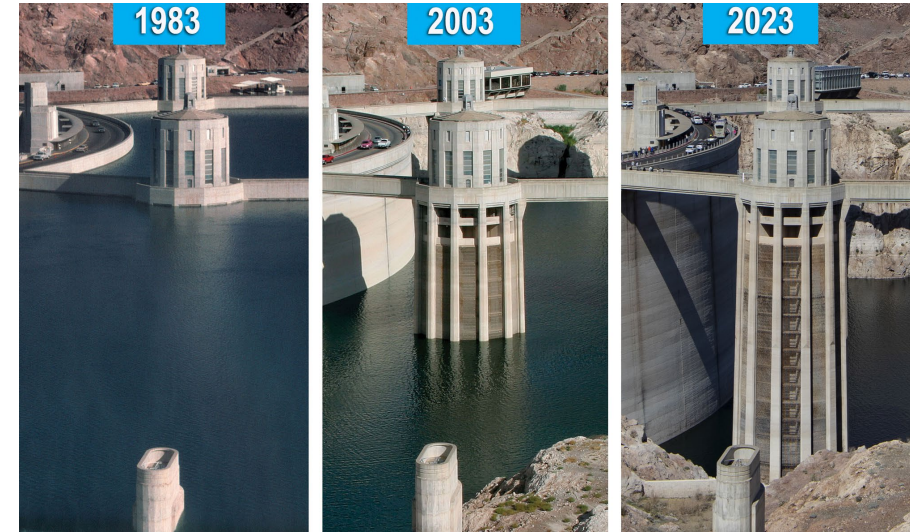


Source: *Data collection network in the online dam monitoring system*

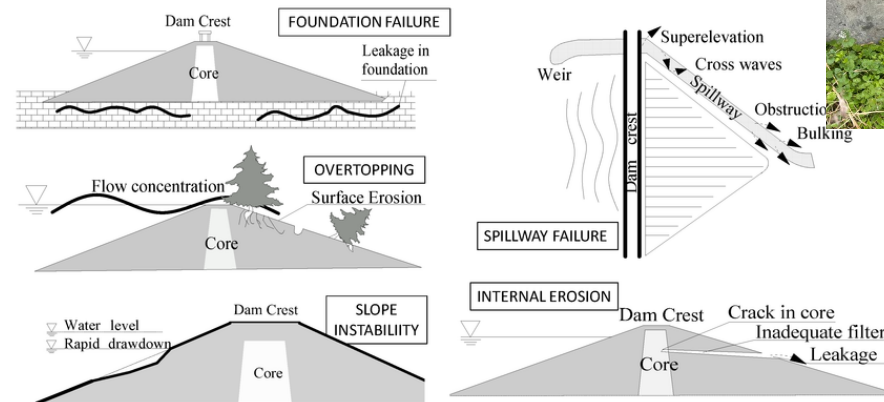
Instrumentation Installation and Monitoring

Instrumentation Data Interpretations

- Current monitoring data can be compared with historic data to detect anomalies or progressive changes
- Gradual changes in pore pressure, settlement, or displacement can indicate potential failure modes
- Changes in patterns could be signal of internal erosion, foundation displacement or settlement, or stress redistribution
- Supports maintenance, rehabilitation and emergency planning decisions



Source: <https://www.snwa.com/water-resources/drought-and-shortage/index.html>



Source: https://www.researchgate.net/figure/Several-failure-modes-of-earth-rock-dams_fig2_324838379





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Laboratory Testing



**CDM
Smith**

Geotechnical Laboratory Testing

— Laboratory Program Design and Test Selection Criteria

Project Considerations:

Project Details: Type, Size, Location, Risk Level, etc.

Design Loads: Type, Magnitude, Frequency, etc.

Project Requirements: Guidelines, Tolerances, etc.

Geotechnical Laboratory Testing

— Laboratory Program Design and Test Selection Criteria

Project Considerations:

Project Details: Type, Size, Location, Risk Level, etc.

Design Loads: Type, Magnitude, Frequency, etc.

Project Requirements: Guidelines, Tolerances, etc.

Geotechnical Considerations:

Subsurface Conditions: Soil/Rock Types, Spatial Variation and heterogeneity, etc.

Regional Hazards: Seismic Sources, Karst Activity, Collapsible Soils, etc.

Presence of Known or Suspected Soil Peculiarities: Intrusions, Slickensides, Fissures, Concretions, etc.

Geotechnical Laboratory Testing

Laboratory Program Design and Test Selection Criteria

<u>Project Considerations:</u>	<u>Material Parameters:</u>
Project Details: Type, Size, Location, Risk Level, etc.	Unit Weight/Density
Design Loads: Type, Magnitude, Frequency, etc.	Grain Size Distribution
Project Requirements: Guidelines, Tolerances, etc.	Atterberg Limits/Moisture Content
	Shear Strength: Friction Angle and Cohesion
<u>Geotechnical Considerations:</u>	Hydraulic Conductivity/Permeability
Subsurface Conditions: Soil/Rock Types, Spatial Variation and heterogeneity, etc.	Compressibility and Compaction
Regional Hazards: Seismic Sources, Karst Activity, Collapsible Soils, etc.	Stress History and Soil Behavior
Presence of Known or Suspected Soil Peculiarities: Intrusions, Slickensides, Fissures, Concretions, etc.	Organic Content, Corrosivity, etc.

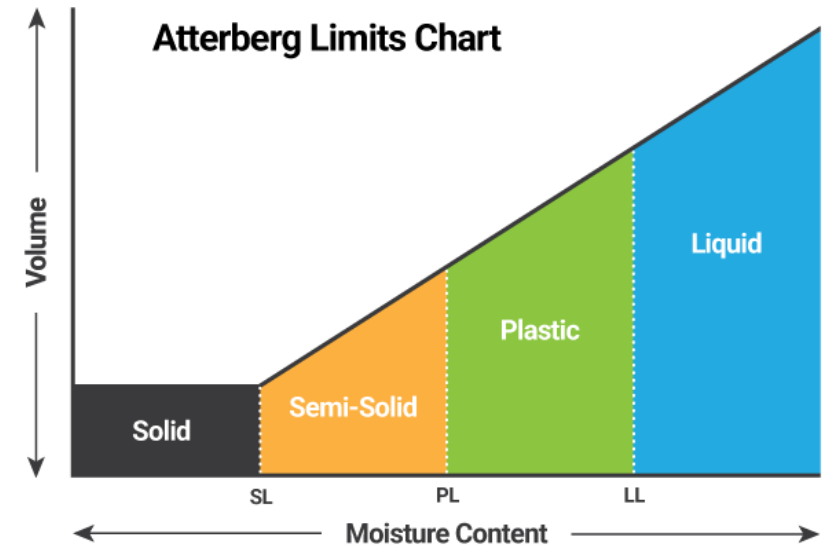
Geotechnical Laboratory Testing

Index tests:

- Atterberg limits
 - Liquid Limit (LL): Plastic – Liquid Transition
 - Plastic Limit (PL): Semi-solid – Plastic Transition
 - Shrinkage Limit (SL): Solid – Semi-solid Transition
 - Plasticity Index (PI): Range of moisture content where the soil is in a plastic state.
 - $PI = LL - PL$



Source: <https://blog.certifiedmtp.com/exploring-atterberg-limits-and-equipment-needed/>



Source: <https://www.substrata.us/blog/atterberg-limits-testing>

Geotechnical Laboratory Testing

Index tests:

- Atterberg limits
- Sieve analysis and hydrometer analysis

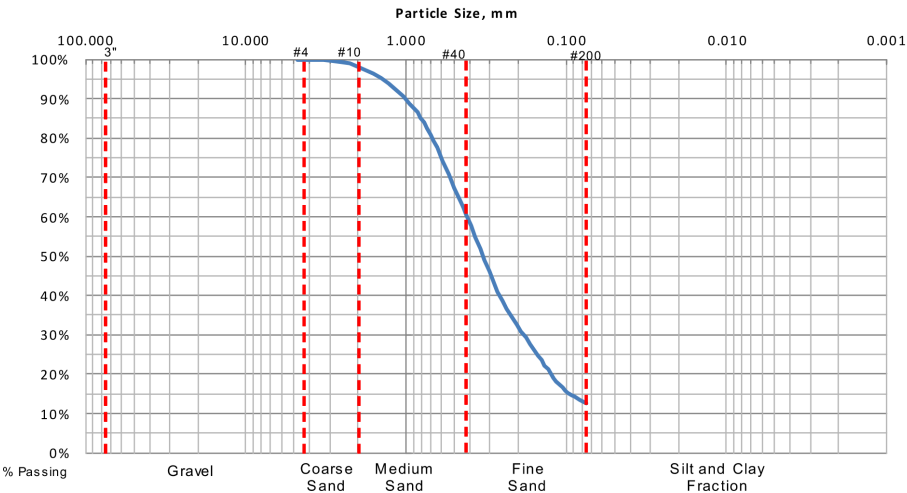


Client PO: 117187

Sample Identification		
S210, East Approach		
Sieve	Size, mm	% Passing
3 in.		
2 in.		
1-1/2 in.		
1 in.		
3/4 in.		
1/2 in.		
3/8 in.		
No. 4	4.75	100
No. 10	2.00	98
No. 20	0.85	87
No. 40	0.425	61
No. 60	0.25	39
No. 100	0.18	25
No. 140	0.106	17
No. 200	0.075	12.7

Material		%
Gravel		0.0
Total Sand		87.3
Coarse Sand		1.8
Medium Sand		37.5
Fine Sand		48.0
Silt and Clay		12.7
Plasticity Characteristics		
Liquid Limit (LL)	Plastic Limit (PL)	Plasticity Index (PI)
NP	NP	NP

TEST RESULTS Report No: 103602-S210 East
Page 1 of 1



Classification	
ASTM	Silty Sand (SM)
AASHTO	A-2-4

Test Method (As Applicable): ASTM D6913, ASTM D1140, ASTM D4318, ASTM D2487, AASHTO M145

Geotechnical Laboratory Testing

Index tests:

- Atterberg limits
- Sieve analysis and hydrometer analysis
- Moisture content



Source: https://www.researchgate.net/figure/Moisture-content-w-testing_fig16_342510129

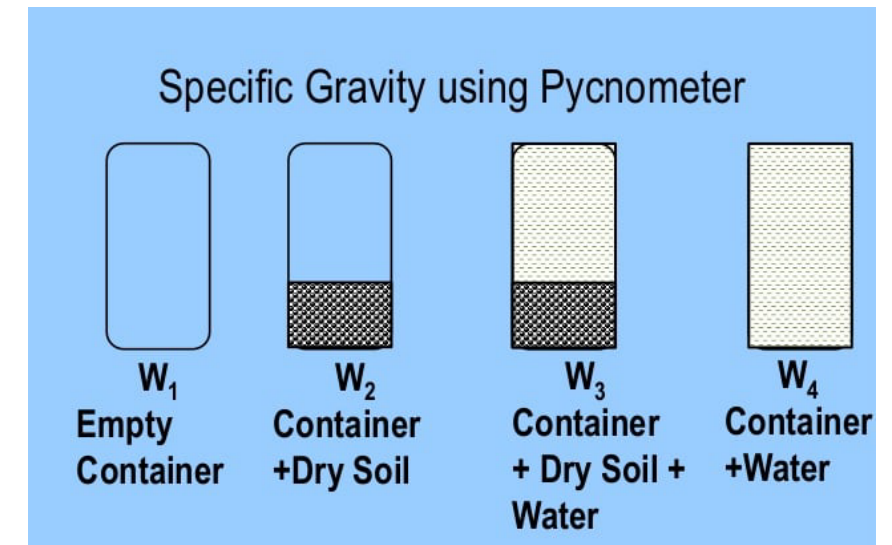
Geotechnical Laboratory Testing

Index tests:

- Atterberg limits
- Sieve analysis and hydrometer analysis
- Moisture content
- Specific gravity
 - Critical for calculating soil or aggregate density, void ratio, and/or degree of saturation



Source: <https://uta.pressbooks.pub/soilmechanics/chapter/55/>



Source: <https://civilarc.com/specific-gravity-soil-pycnometer-method/>

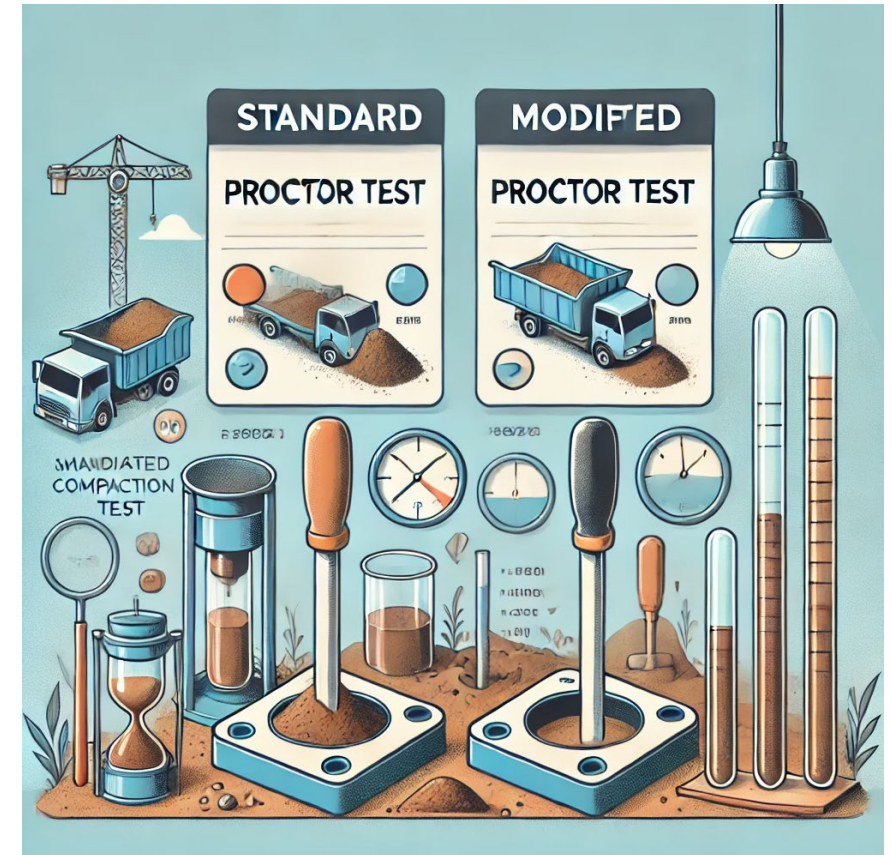
Geotechnical Laboratory Testing

Index tests:

- Atterberg limits
- Sieve analysis and hydrometer analysis
- Moisture content
- Specific gravity
- Bulk and dry density
- Comparing laboratory specific gravity data and field measurements, such as in-place density tests, is essential to verify that compaction and material placement conform to design specifications



Source: <https://blog.certifiedmtp.com/nuclear-density-gauge-unlocking-the-benefits/>



Source: <https://blog.certifiedmtp.com/standard-proctor-and-modified-proctor-tests/>

Geotechnical Laboratory Testing

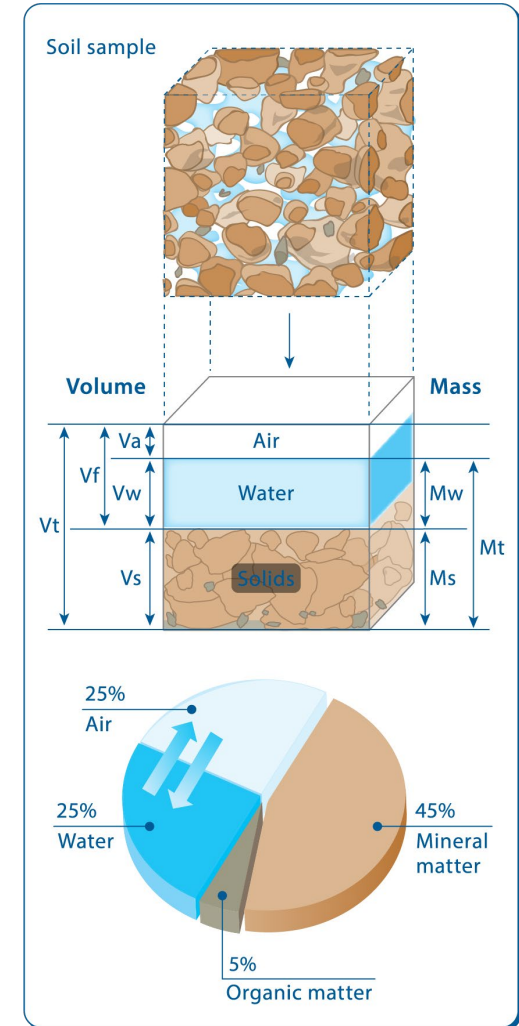
Index tests:

- Atterberg limits,
- Sieve analysis and hydrometer analysis,
- Moisture content,
- Specific gravity, and
- Bulk and dry density
- Organic Content Test

% Organic Matter (dry weight) via Lab Test

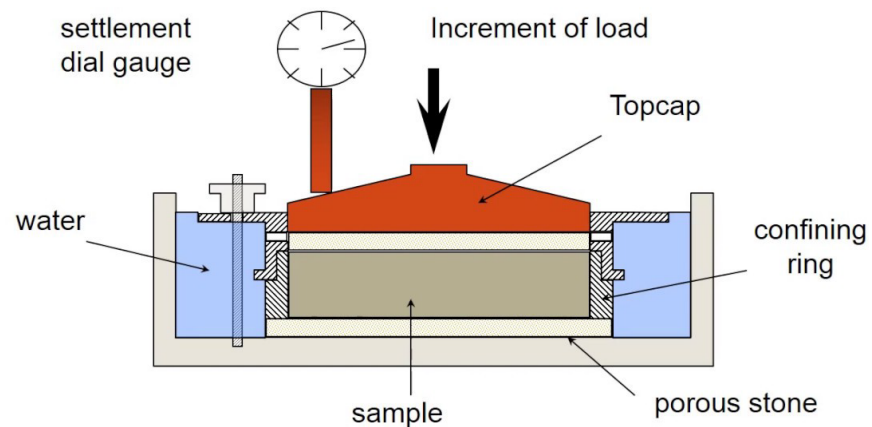


Source: <https://www.slideshare.net/slideshow/managing-organic-matter-for-soil-health-and-fertility/4281226543033#12>



Geotechnical Laboratory Testing

- Advanced soil testing:
 - 1-D consolidation test using incremental loading



Source: [Consolidation in Soil Mechanics](https://www.vertexinstruments.com/consolidation)



Source: <https://www.vertexinstruments.com/consolidation> -test-apparatus-three-gang/consolidation -test-apparatus-

2

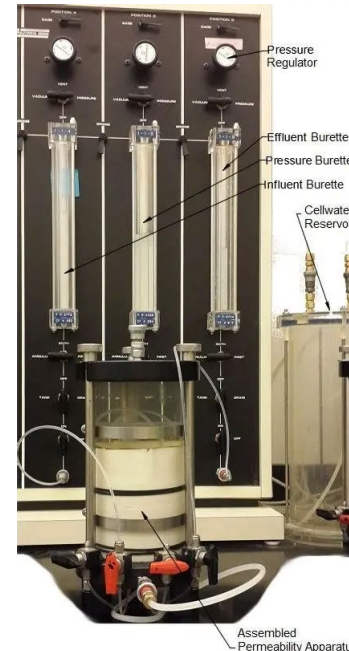
Geotechnical Laboratory Testing

Advanced soil testing:

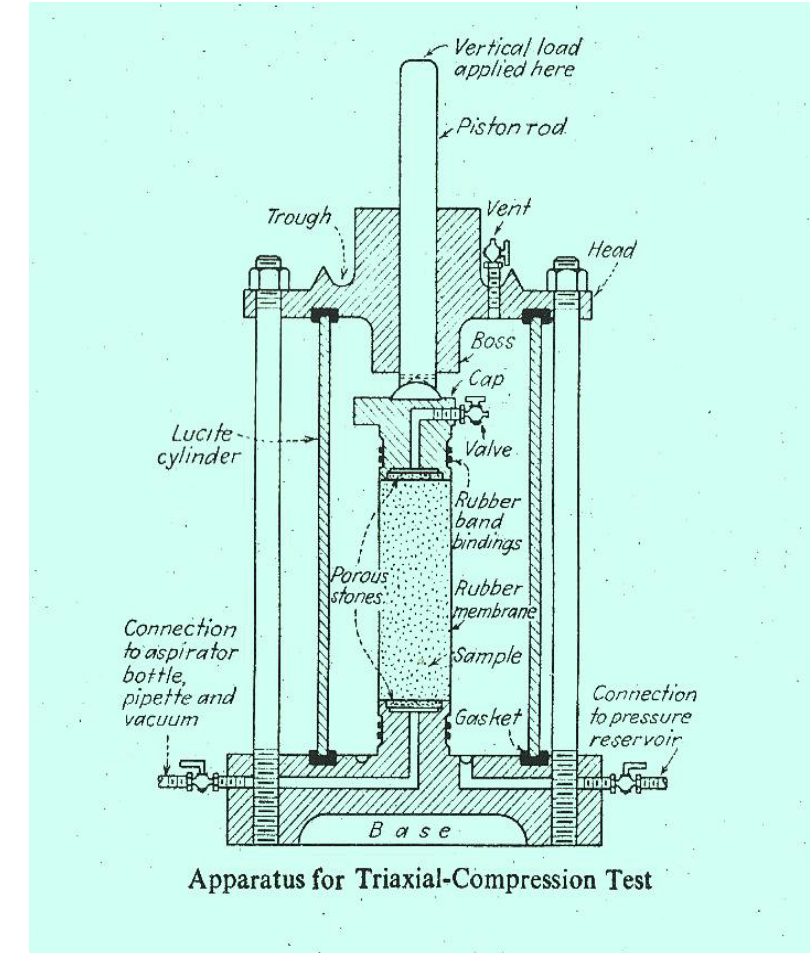
- 1-D consolidation test using incremental loading
- Triaxial compression tests
 - Consolidated-Undrained (CIU) with/without pore pressure measurement
 - Unconsolidated-Undrained (UU)
 - Consolidated-Drained (CD)



Source: <https://www.test-lab.com/strength-testing>



Source: https://www.researchgate.net/figure/Hydraulic-conductivity-cell-and-pressure-panel-used-in-this-study_fig6_336497919

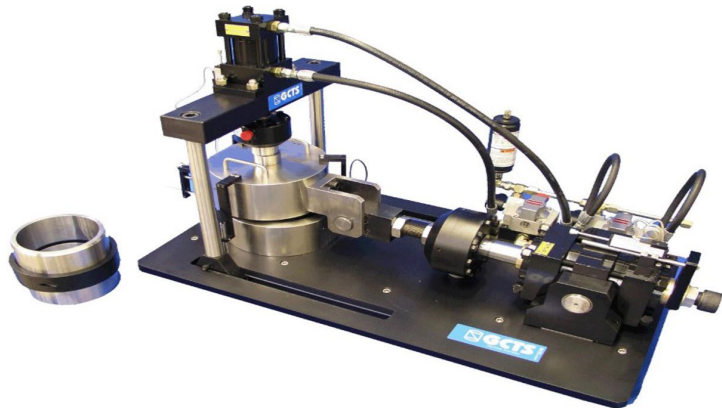


Source: <https://www.theconstructioncivil.org.com/triaxial-compression-test-of-soils-procedure/>

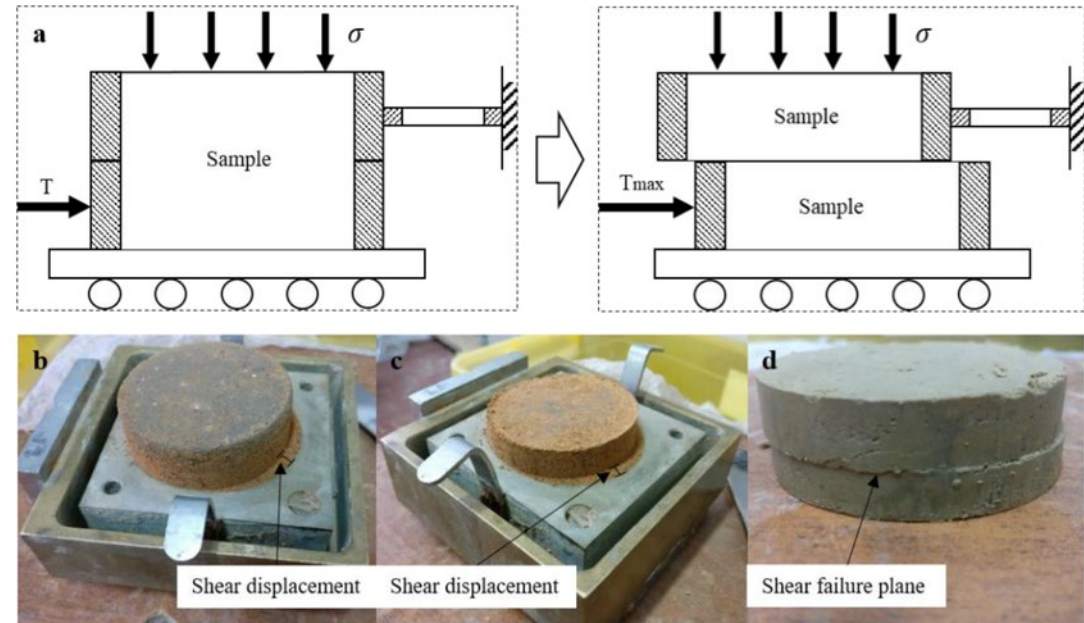
Geotechnical Laboratory Testing

Advanced soil testing:

- One dimensional consolidation test using incremental loading
- Triaxial compression tests
 - Consolidated undrained (CIU) triaxial compression with pore pressure measurement
 - Unconsolidated Undrained (UU)
 - Consolidated Drained (CD)
- Direct Shear Test



Source: <https://civilseek.com/direct-shear-test/>



Source: Direct shear test. (a) Schematic diagram of the direct shear test. (b)... | Download Scientific Diagram

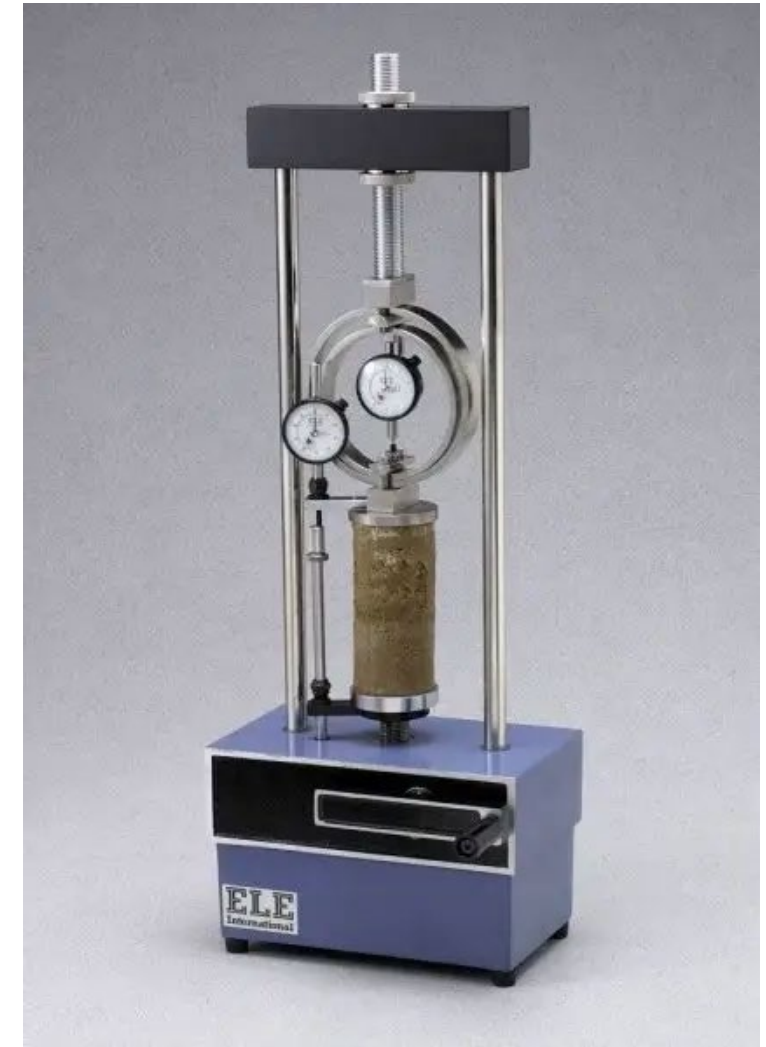
Geotechnical Laboratory Testing

— Advanced soil testing:

- One dimensional consolidation test using incremental loading
- Triaxial compression tests
 - Consolidated undrained (CIU) with/without pore pressure measurement
 - Unconsolidated Undrained (UU)
 - Consolidated Drained (CD)
- Direct Shear Test
- Unconfined compression tests



Source: Unconfined Compression Load Frame / Test System Geocomp
[Laboratory Testing - Soil Testing] - Geotechnica

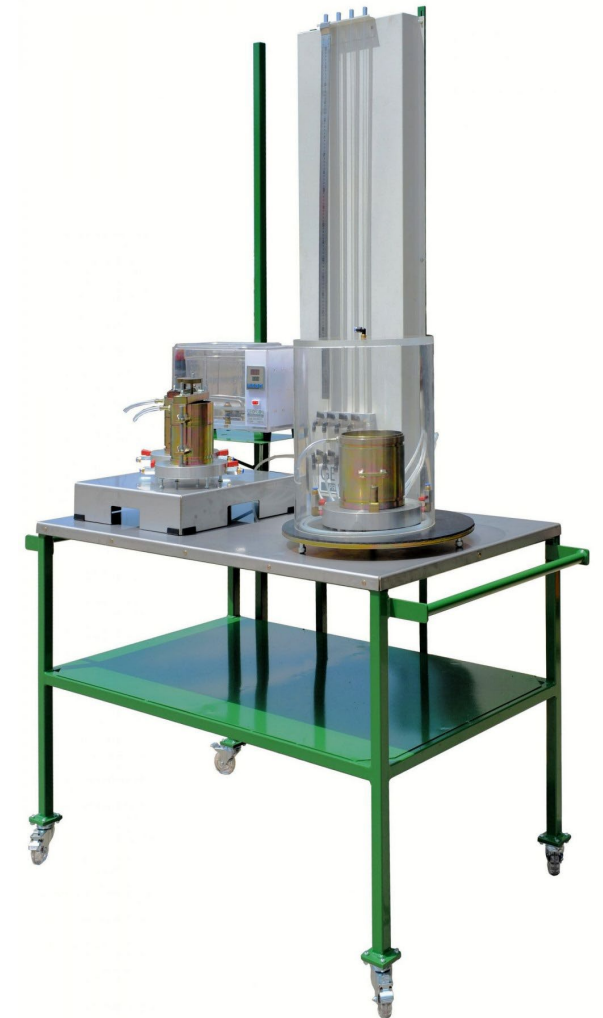


Source: <https://www.ele.com/product/1> -unconfined-compression-tester-hand-operated

Geotechnical Laboratory Testing

— Advanced soil testing:

- One dimensional consolidation test using incremental loading
- Triaxial compression tests
 - Consolidated undrained (CIU) with/without pore pressure measurement
 - Unconsolidated Undrained (UU)
 - Consolidated Drained (CD)
- Direct Shear Test
- Unconfined compression tests
- Permeability test (constant head and falling head)



Source: <https://www.geo-con.com.au/product/constant-falling-head-permeability-apparatus-2/>

Structural Laboratory Testing

- Concrete and Structural Material Testing
 - Concrete core sampling and compression testing



Source: <https://specializedtesting.com/field-services/concrete-core-drilling/>



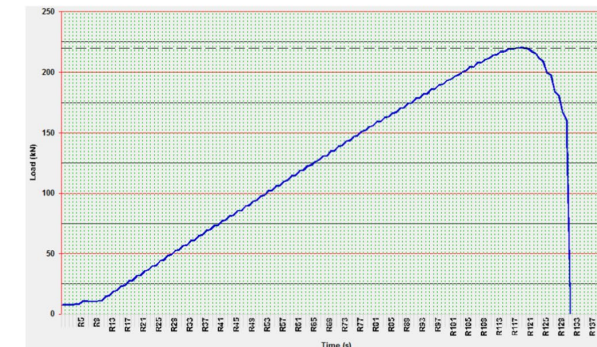
Source: <https://certifiedmtp.com/concrete-compression-test-machine-400k-1780kn-i7-controller/>



Mount concrete specimen in machine



Compress the specimen until it fails



Peak load obtained from test machine

$$f_c = \frac{P}{A}$$

Where
 f_c is the compressive strength of concrete
 P is the peak load
 A is the area of loaded surface



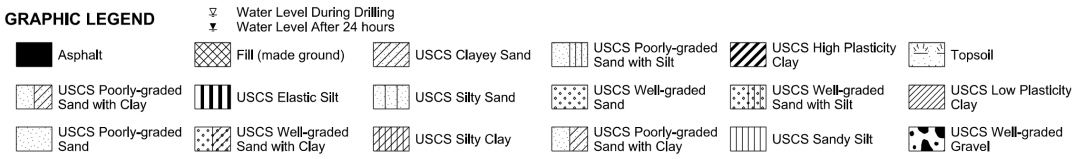
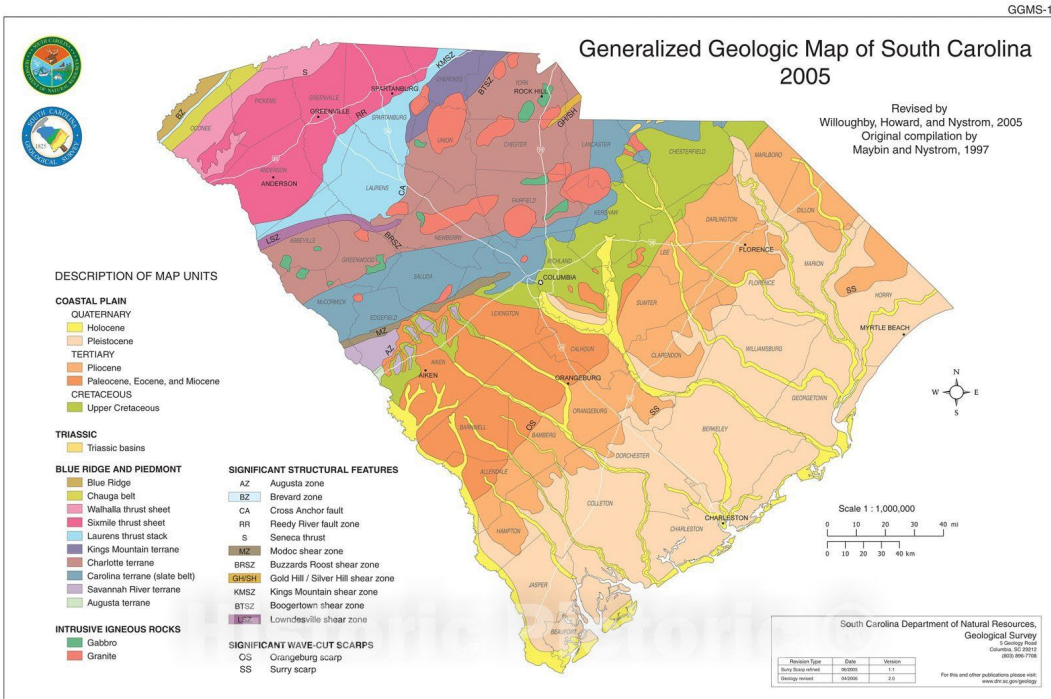
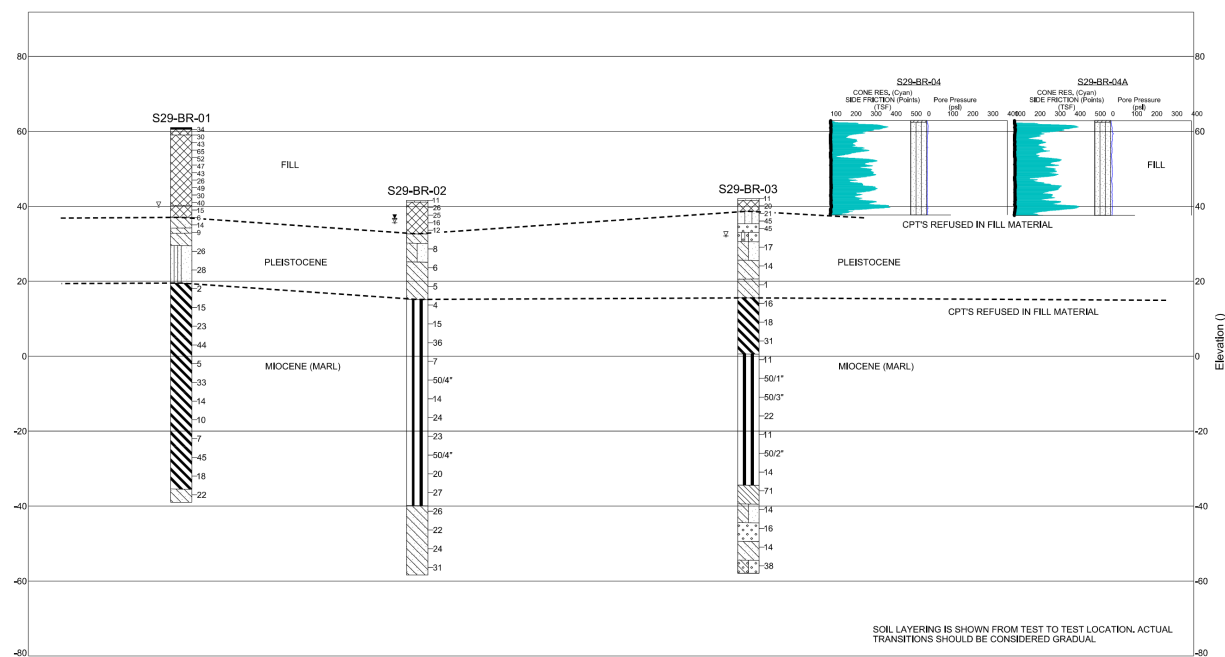
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Data Interpretation



Data Interpretation

- Determine soil parameters for analysis
 - Soil stratigraphy and material classification (e.g., soil fences)
 - Soil properties and correlations



Data Interpretation

■ Seepage Monitoring

- Visual Inspection
 - Identify location and surface area of seepage. Is the area growing?
 - Estimate seepage volumes and flow rates. Is it increasing with time?
 - Evaluate clarity/turbidity of seepage water
 - Locate dam features near seepage area that may be causing or may be impacted by the seepage.
- Instrumentation Data Interpretation
 - Piezometer and digital pressure sensor readings
 - Are there recent groundwater fluctuations?
 - Are there sudden drops in groundwater across the dam that do not match embankment features, e.g. a clay core?

Data Interpretation

— Settlement Monitoring

- Visual Inspection
 - Identify settlement features, locations, and trends
 - Are they localized depressions, or do they follow linear trends?
 - If linear, are they parallel or perpendicular to the embankment?
 - Are they above a dam feature that could produce settlement?
 - Is there evidence of settlement around a structure supported by deep foundations, e.g. around a spillway?
- Instrumentation Data Interpretation
 - Surveyor mapping, LiDAR mapping, Drone surveys, etc.
 - Are there global settlement trends, i.e. sagging?
 - Are the settlement features growing with time?
 - Is the growth rate increasing or decreasing?

Data Interpretation

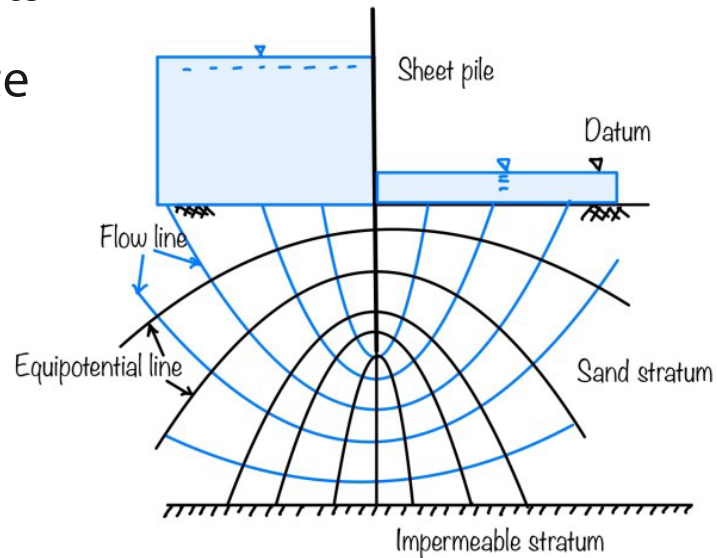
— Structural Monitoring

- Visual Inspection
 - Identify signs of deterioration, damage, fatigue, etc
 - Is there cracking or other signs of stress failures?
 - Is there spalling, rusting, or signs of material degradation?
 - Are there signs of movement?
- Instrumentation Data Interpretation
 - Surveys, strain gauges, crack monitoring gauges, etc.
 - Are the cracks stable or growing?
 - Is there excessive strain recorded?
 - Is there evidence of past settlement or progressive movement?

Geotechnical Analyses

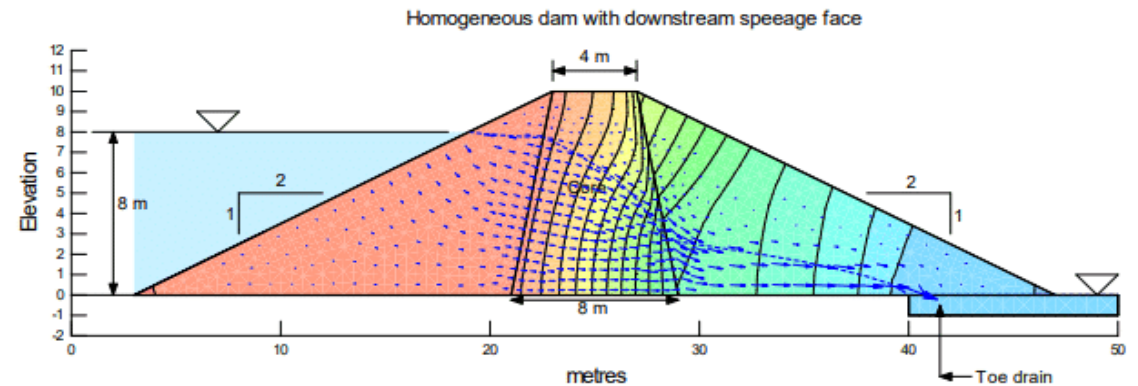
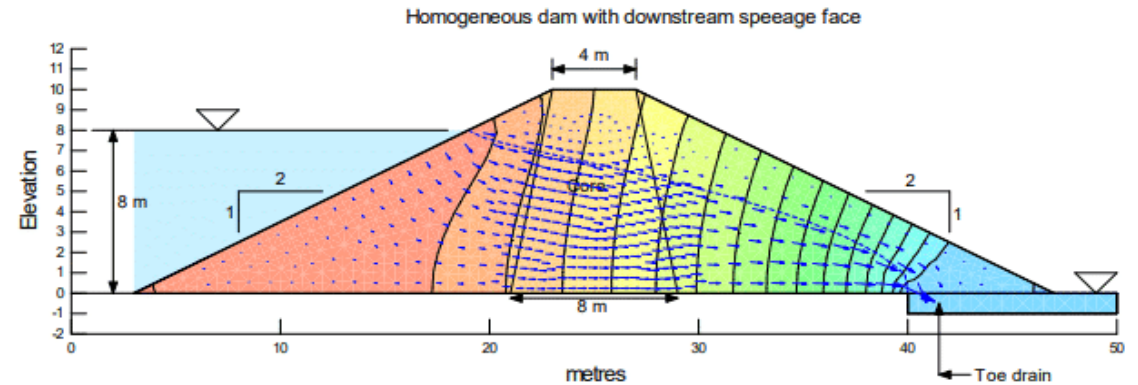
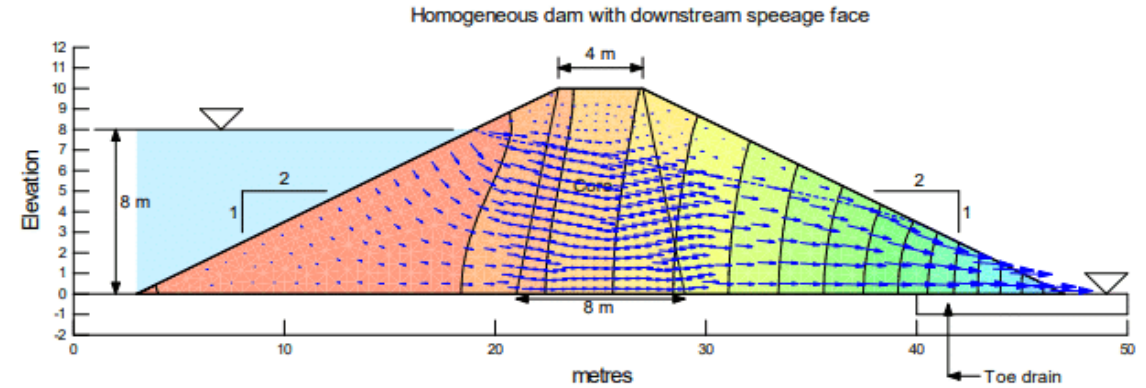
Seepage Analyses

- Steady-State or Transient analyses
- Phreatic surface
- Seepage daylighting
- Exit gradients
- Seepage rate



2-D seepage flow

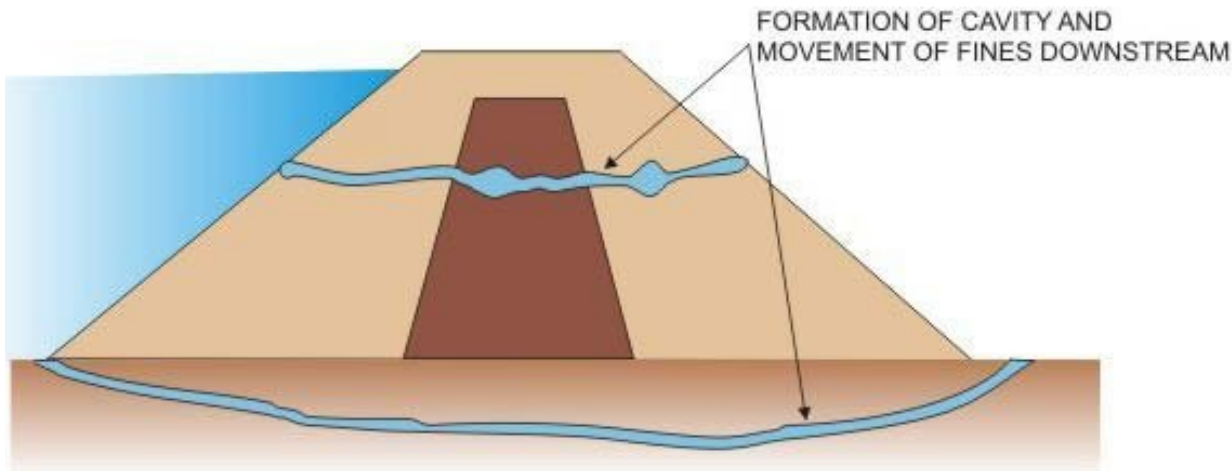
Source: <https://www.eigenplus.com/seepage-flow/>



Source: <https://www.sequent.com/seepage-through-an-earth-dam/>

Geotechnical Analyses

- Seepage Analyses
- Internal Erosion and Piping Potential



Source: https://www.researchgate.net/figure/internal-erosion-and-piping-through-dam-body-and-foundation_fig14_330113598

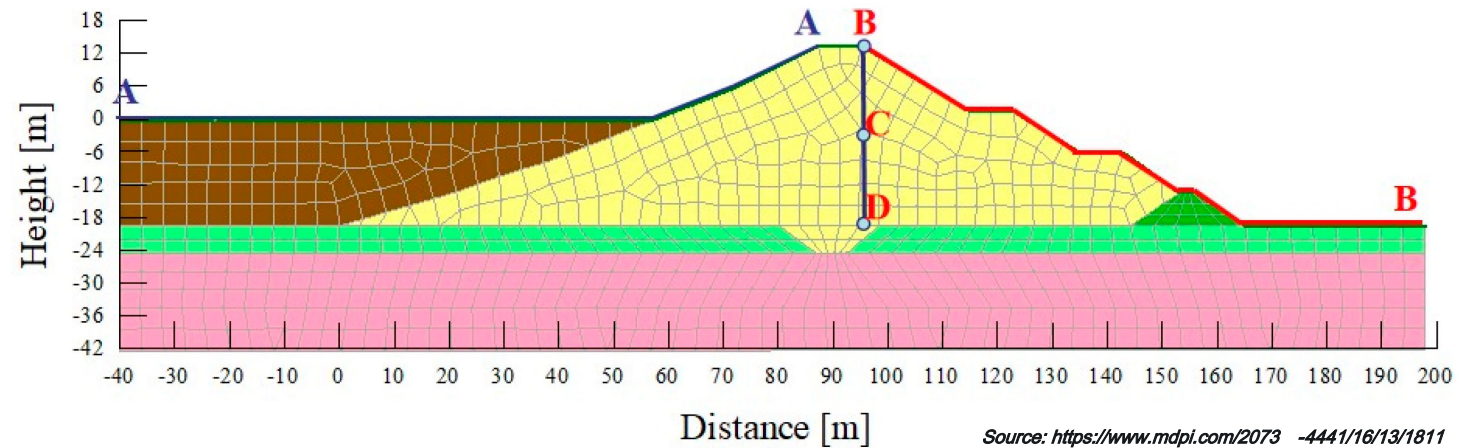
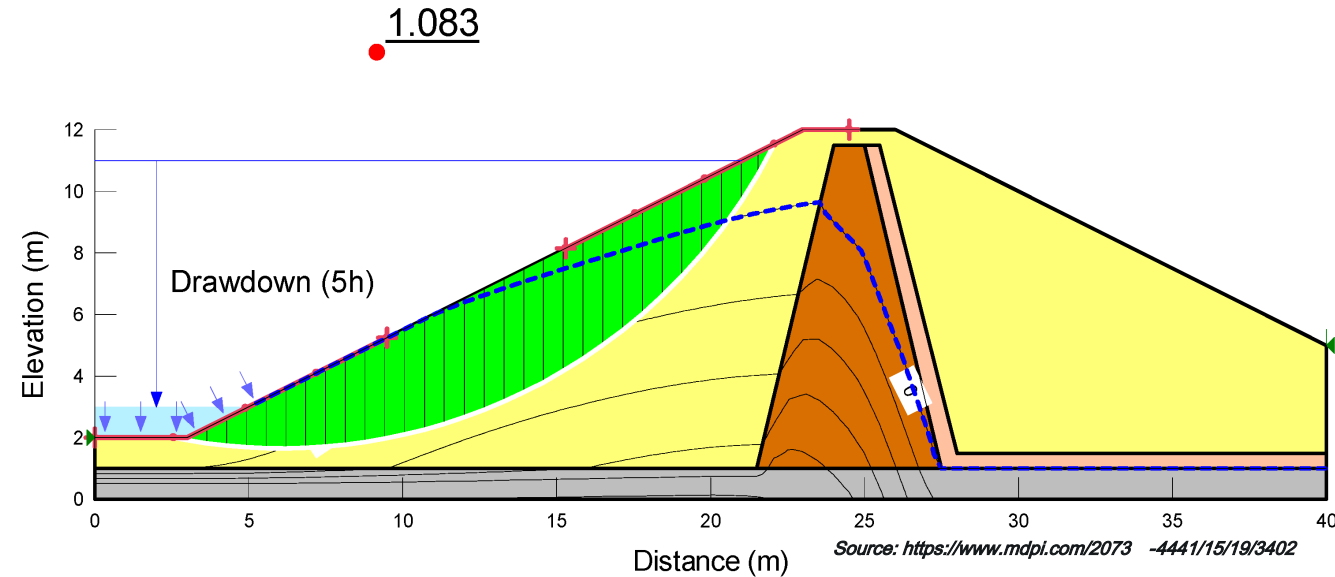


Source: <http://geoengineering.org> (donated by Jeffrey A. Farrar)

Geotechnical Analyses

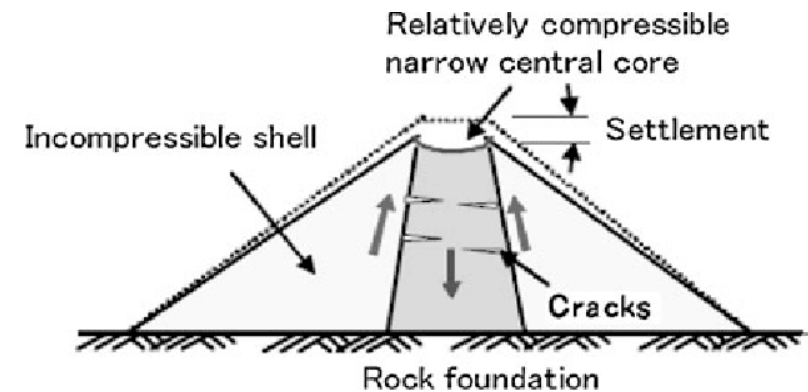
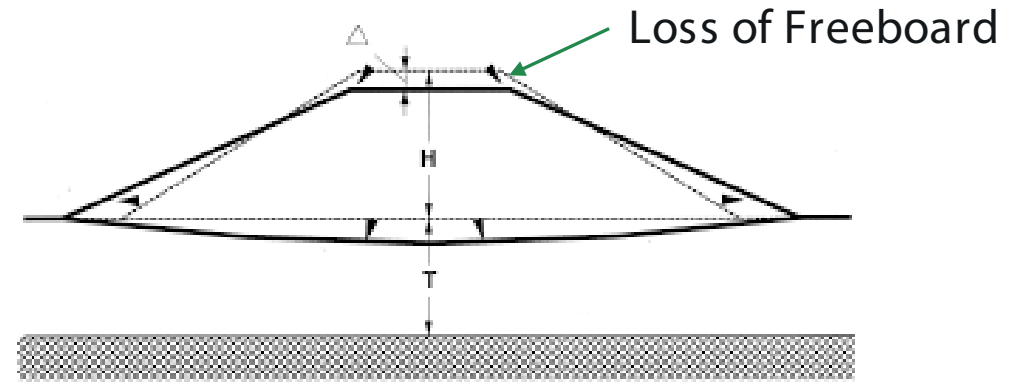
- Seepage Analyses
- Internal Erosion and Piping Potential
- Slope Stability

- Static slope stability: short-term and long-term conditions,
- Rapid drawdown slope stability,
- Pseudo-static slope stability,
- Basal and interface sliding,
- Evaluate upstream and downstream.



Geotechnical Analyses

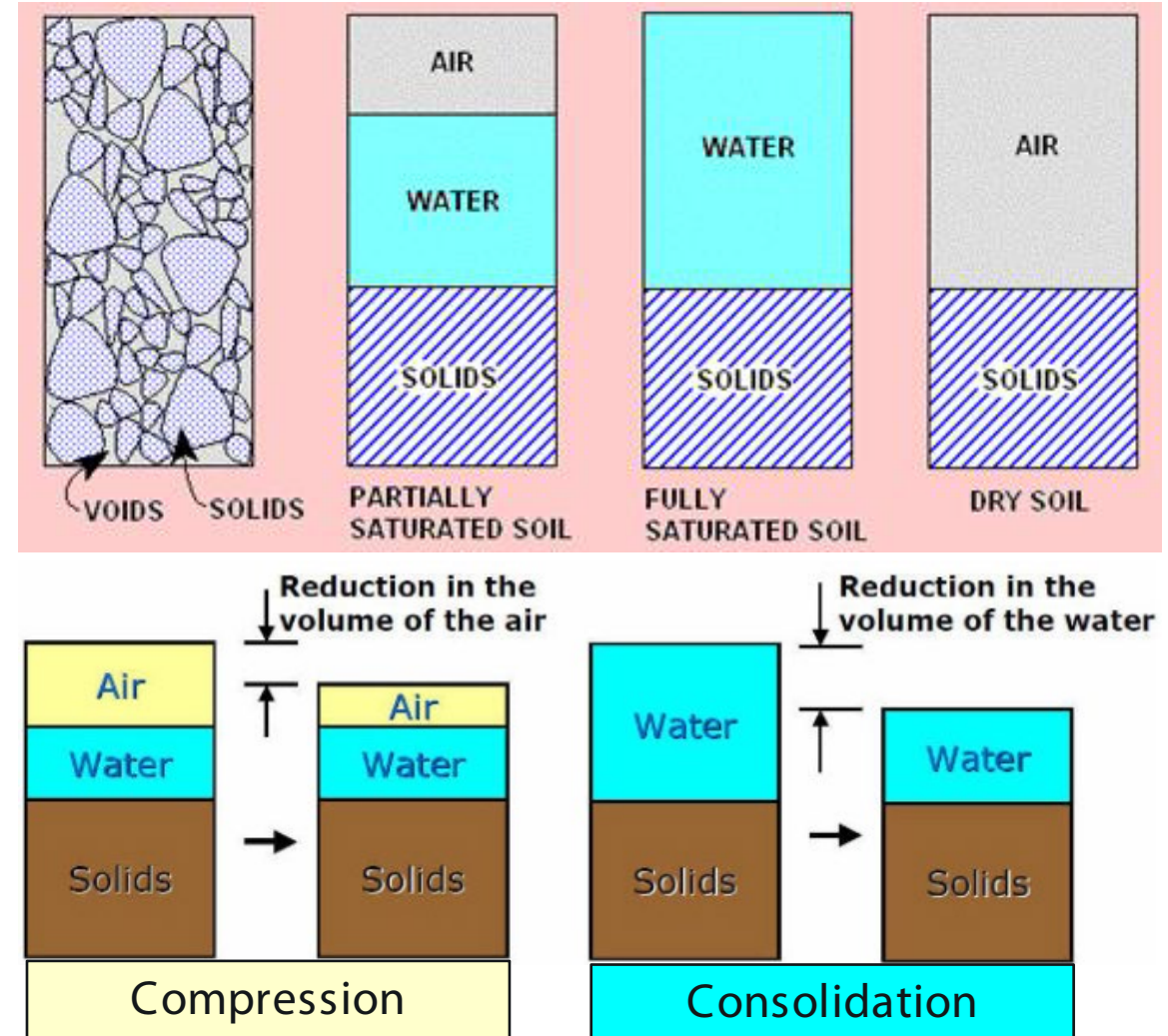
- Seepage Analyses
- Internal Erosion and Piping Potential
- Slope Stability
- Settlement Analyses



Source: <https://www.researchgate.net/figure/Differential-settlement-and-cracking-in-core-for-embankment-dam-Ohne-and-Narita-1977>

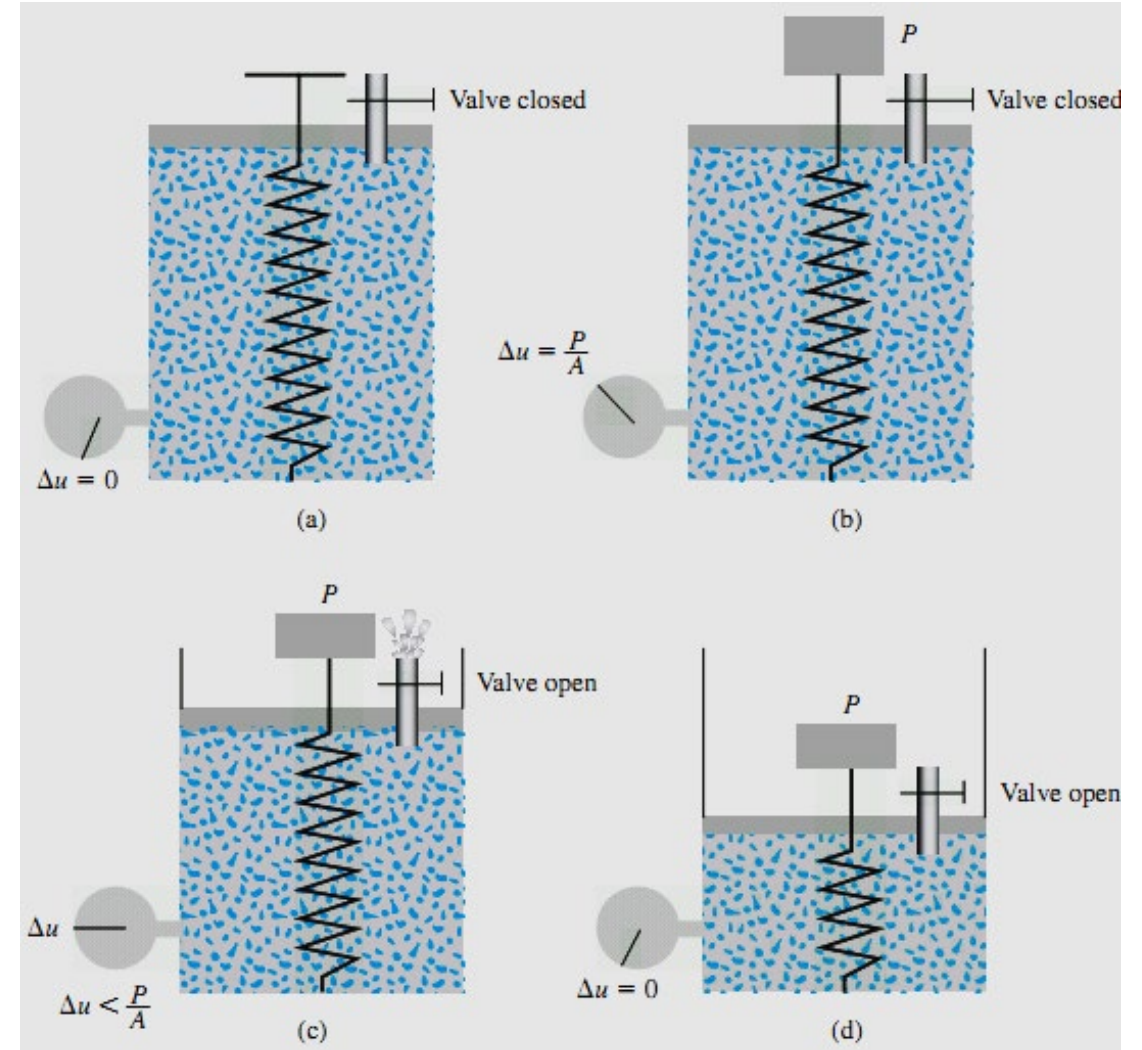
Geotechnical Analyses

- Seepage Analyses
- Internal Erosion and Piping Potential
- Slope Stability
- Settlement Analyses
 - Compression/Compaction
 - Consolidation



Geotechnical Analyses

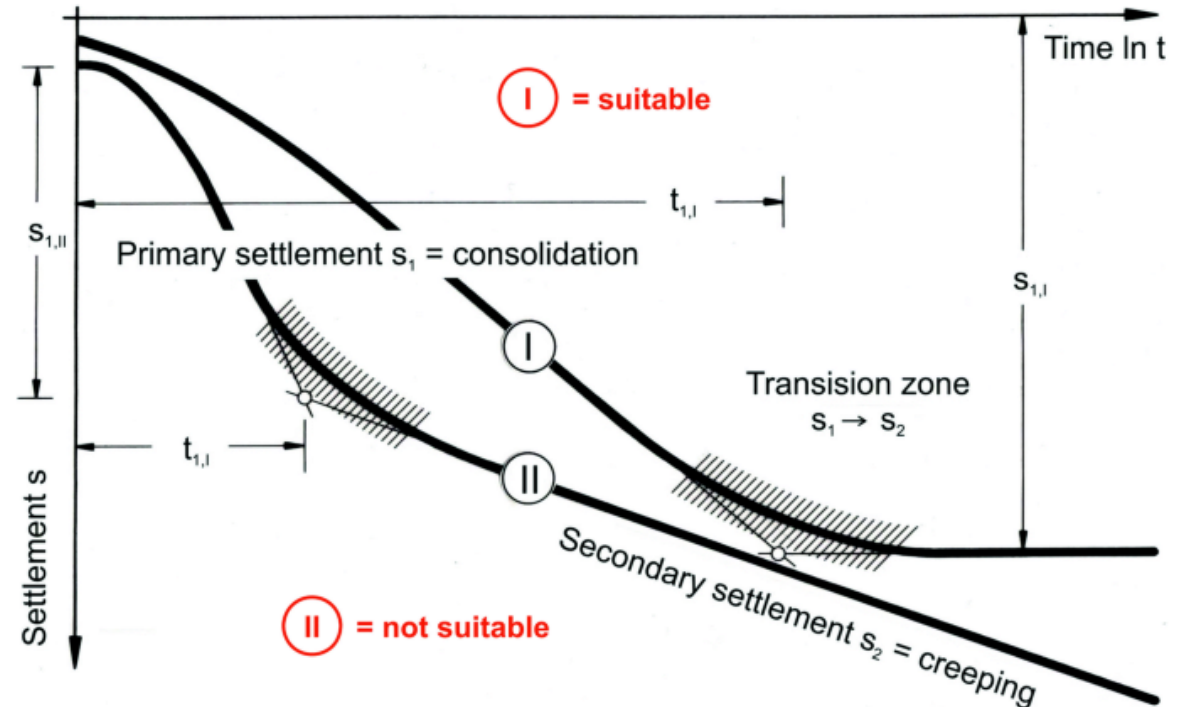
- Seepage Analyses
- Internal Erosion and Piping Potential
- Slope Stability
- Settlement Analyses
 - Compression/Compaction
 - Consolidation



Source: https://www.researchgate.net/figure/Spring-cylinder-model-for-consolidation-in-saturated-clay_fig64_324162566

Geotechnical Analyses

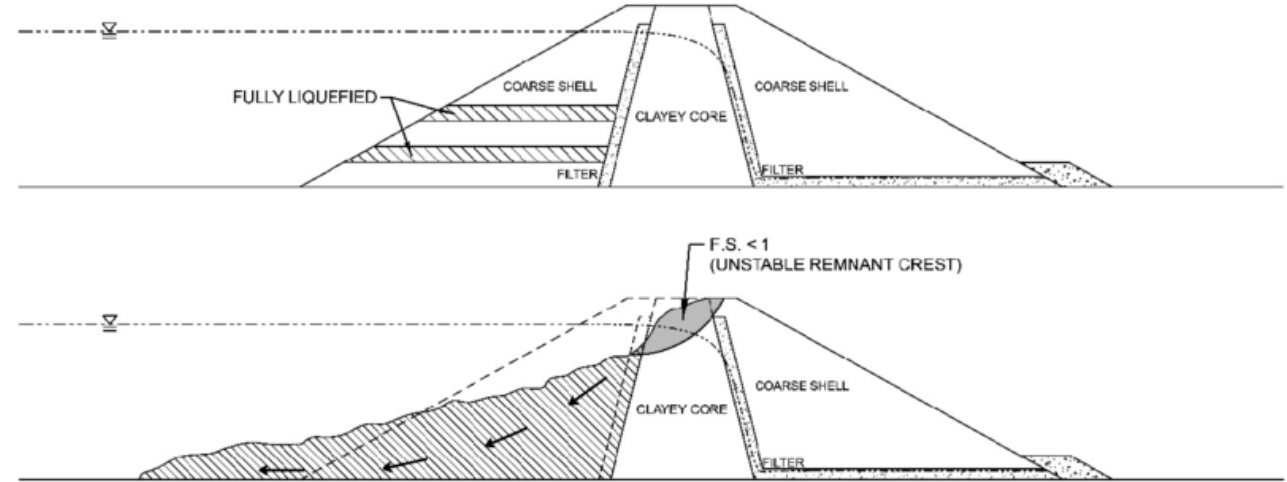
- Seepage Analyses
- Internal Erosion and Piping Potential
- Slope Stability
- Settlement Analyses
 - Compression/Compaction
 - Consolidation
 - Creep/Secondary settlement



Source: https://link.springer.com/chapter/10.1007/978-3-030-34184-8_9

Geotechnical Analyses

- Seepage Analyses
- Internal Erosion and Piping Potential
- Slope Stability
- Settlement Analyses
- Liquefaction Hazard Analyses
 - Susceptibility to liquefaction and cyclic mobility
 - Post-seismic settlement
 - Strength loss and residual shear strength
 - Lateral spreading and flow failures
 - Seismic deformation



Source: https://www.researchgate.net/figure/An-illustration-of-a-Liquefaction-Induced-Upstream-Flow-Slide-In-an-Earthen-Dam_fig1_363809055



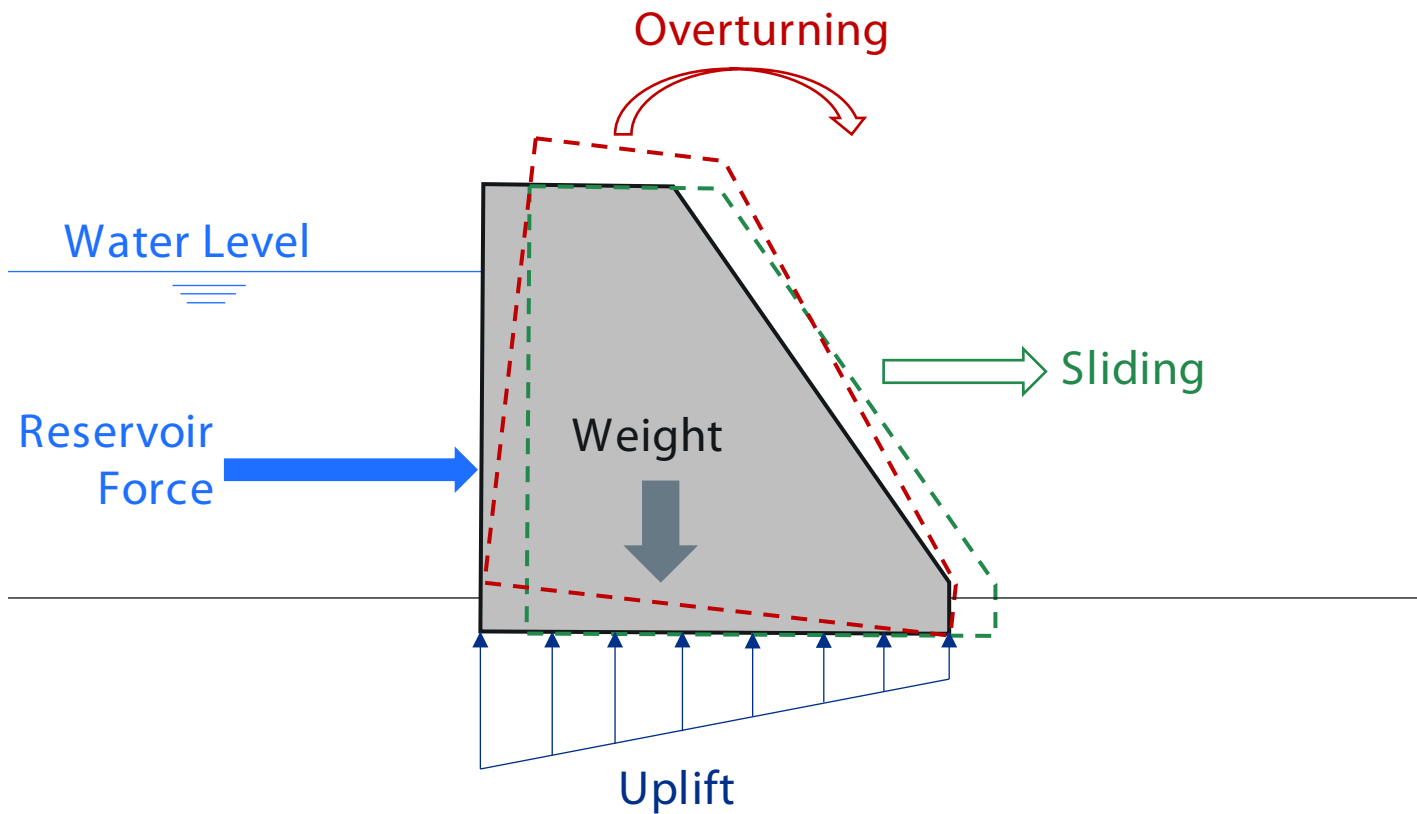
Source: <https://depts.washington.edu/liquefy/html/what/what1.html>

Structural Analyses

■ Stability of Concrete Structures

Stability Requirements

- Failure Types



Structural Analyses

■ Stability of Concrete Structures

Load Condition Categories

- Table 3-1 Load Condition Probabilities (EM- 1110-2-2100)

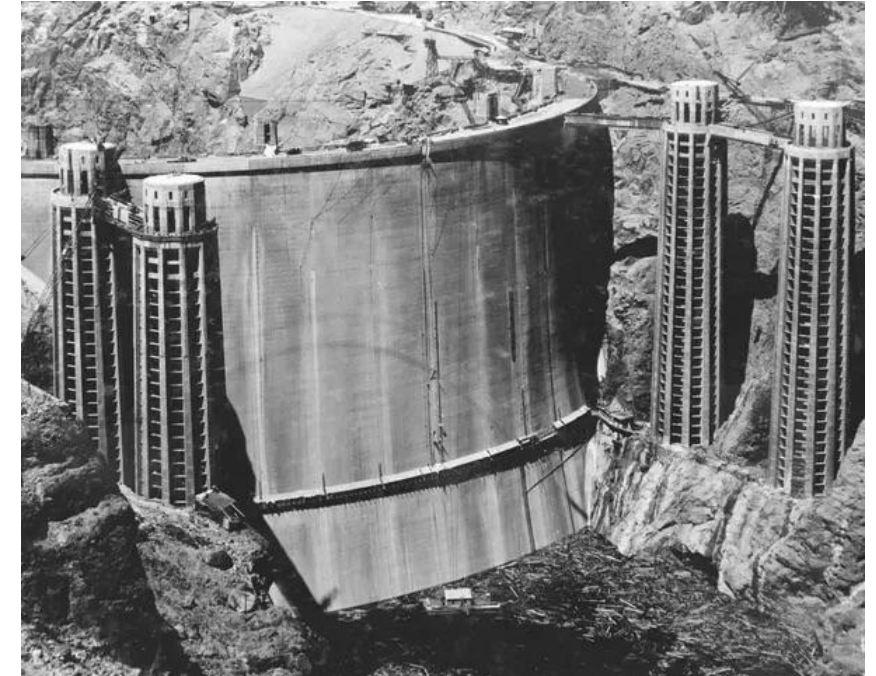
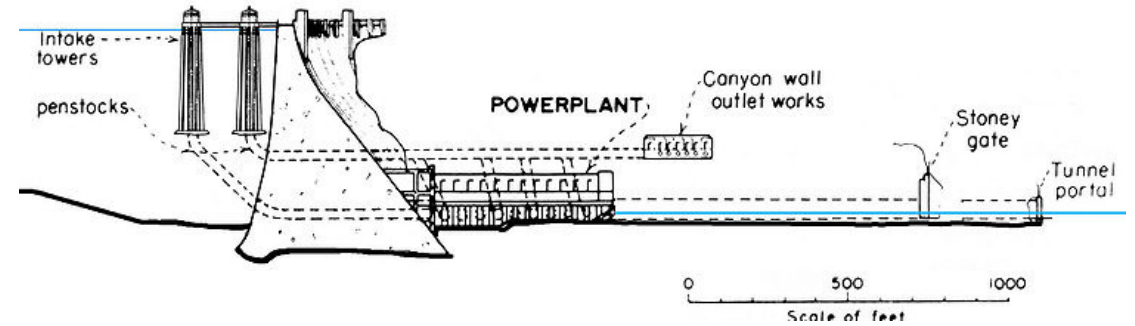
<u>Load Condition Categories</u>	<u>Annual Probability</u>	<u>Return Period</u>
Usual	≥ 0.10	≤ 10 years
Unusual	$< 0.10 \geq 0.0033$	> 10 years ≤ 300 years
Extreme	< 0.0033	> 300 years

Structural Analyses

■ Stability of Concrete Structures

Load Condition Categories (EM-1110-2-2100)

- Usual
 - Related to the primary function of a structure
 - Can be expected to occur frequently
- Unusual
 - Infrequent occurrence
 - Construction, maintenance loads – Temporary structures
- Extreme
 - Highly improbable – Emergency conditions
 - Natural disasters (e.g. earthquakes or flooding) having a frequency of occurrence exceeding the service life of the structure
 - Combination of unusual loading events



Source: <https://entirelandscapes.space/Hoover-dam-intake-towers>

Structural Analyses

■ Stability of Concrete Structures

Loading Conditions and Loading-Condition Classification (EM-1110-2-2100)

- Purpose: Classify each load condition to comply with Table 3-1 definitions for usual, unusual, and extreme (U/UN/E)
- Normal operating pool
 - Water surface elevations (WSE) which represent 10-year return period
- Coincident pool
 - Temporal average pool conditions – used for seismic design
 - Temporal average pool – pool elevation that is equaled or exceeded 50% of the time for 1 year

Structural Analyses

- Stability of Concrete Structures (EM-1110-2-2100)
 - Reference to structure specific USACE engineering manuals

Table B-11 Spillway Loading-Condition Classification
Structure Type: Spillway – Approach Channel Walls EM 1110-2-2400

Load Case	Loading Description	Classification
I	Channel Empty	U
II	Partial Sudden Drawdown, PMF	E
III	Sudden Pool Rise, PMF	E
IVA	Coincident Pool + OBE	UN
IVB	Coincident Pool + MDE	E

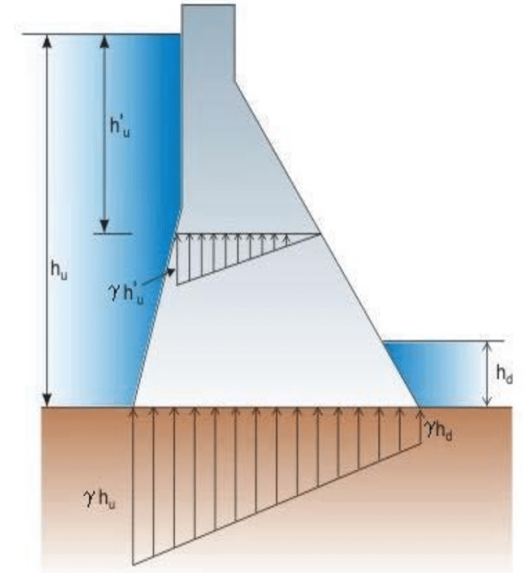
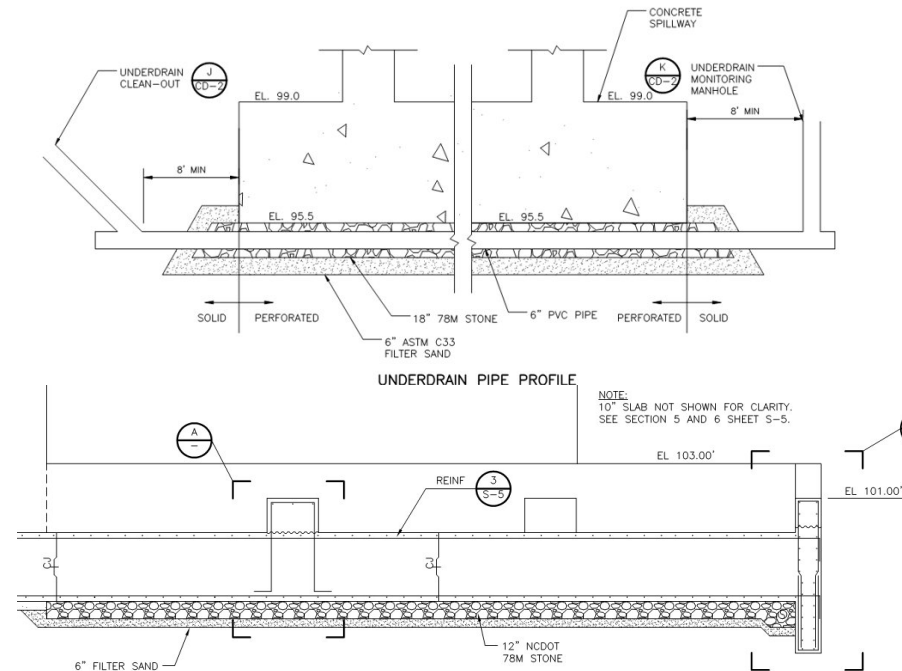
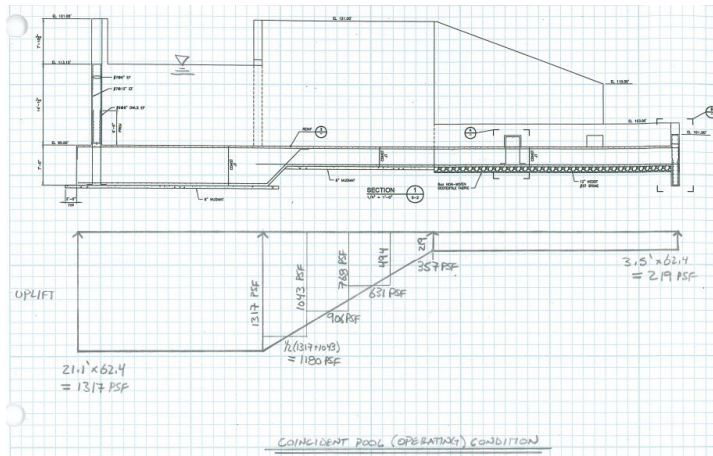
Table B-13 Spillway Loading-Condition Classification
Structure Type: Spillway – Basin Walls EM 1110-2-2400

Load Case	Loading Description	Classification
I	Construction or Maintenance	UN
II	Rapid Closure of Gates	UN
III	MDF Discharge Conditions	U/UN/E
IVA	Coincident Pool + OBE	UN
IVB	Coincident Pool + MDE	E

Structural Analyses

Uplift Pressures

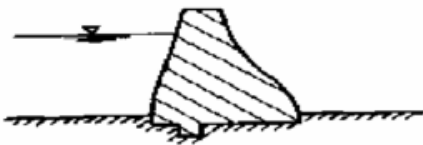
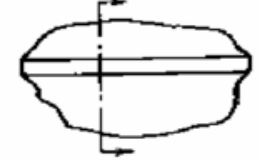
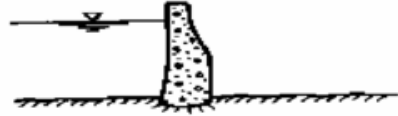
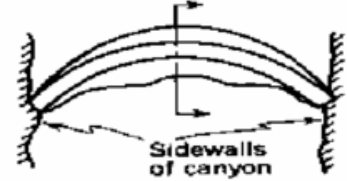
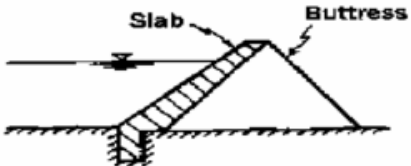
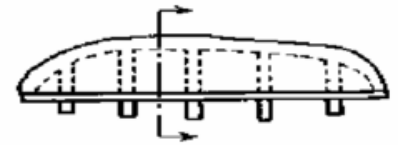
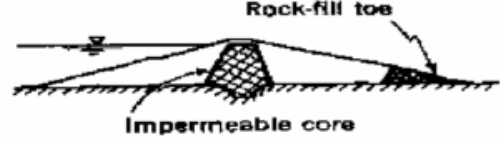
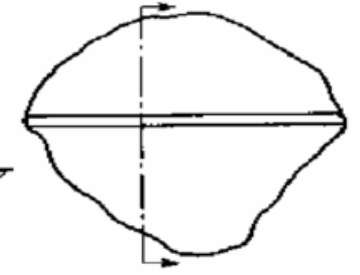
- Uplift pressures for design load conditions are known, or can be extrapolated for design load condition based on measured uplift pressure data
- Foundation drains reduce uplift pressure on structures



Source: <https://www.researchgate.net/figure/fig3> -illustrates -the-uplift -pressure-on-a-concrete-gravity-dams-non-overflow-section_fig2_355077253

Structural Analyses

Types of Dams:

Type	Material	Sectional View	Plan (Top View)
Gravity	Concrete, rubble masonry		
Arch	Concrete		
Buttress	Concrete also timber and steel)		
Embankment	Earth or rock		

Source: https://www.researchgate.net/figure/Different-types-of-concrete-dams_fig1_355077253

Structural Analyses

Types of Gravity Dams

- Material: Concrete and composite
- Shape: Straight and curved
- Height: Low, medium and high gravity dams



Source: [https://www.britannica.com/technology/gravity](https://www.britannica.com/technology/gravity-dam) -dam



Source: [https://thingstodoinlasvegas.com/hover](https://thingstodoinlasvegas.com/hover-dam-tours/) -dam-tours/

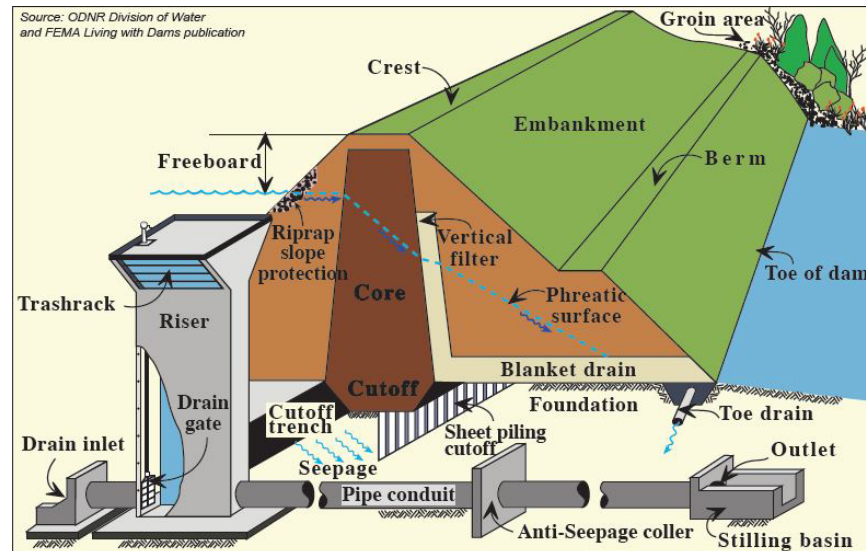
Structural Analyses

■ Stability of Appurtenant Structures

- Spillways
- Inlet structures
- Outlet works
- Gates and valves, etc.



Source: <https://geotechpedia.com/News/Show/953/Oroville> -Dam-Spillway -Failure



Source: <https://www.ubcdams.org/193/Typical> -Dam-Design



Source: <https://interestingengineering.com/innovation/dam> -failures -common-reasons-for-complications



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Next Steps



Next Steps

- If issues are identified that could adversely impact dam safety
 - Recommend monitoring and/or maintenance
 - Develop design alternatives to mitigate identified issues
 - Evaluate alternatives and provide recommendation with sufficient detail to serve as basis for final design



Source: https://www.army.mil/article/245599/major_maintenance_completed_at_lock_and_dam_4



Next Steps

- If seepage and/or internal erosion and piping potential issues are identified:
 - Record location were encountered and describe the seepage
 - Clear water versus cloudy, flow rate, etc
 - Signs of piping, boils, turbidity
 - Increase monitoring frequency
 - Lower reservoir level to reduce hydraulic pressure
 - Install sandbags and temporary drains to control seepage and prevent erosion
 - Engineers should perform seepage analysis and assess internal erosion risk



Next Steps

- If slope stability issues are identified:
 - Record location where encountered, take photographs, and describe the type of instability
 - Longitudinal or traverse cracks, slides, bulges, depressions
 - Increase monitoring by adding survey points to track displacement
 - Lower reservoir level to reduce driving forces on the dam slope
 - Stabilize the toe with temporary berms or riprap
 - Engineers should perform slope stability analysis under critical loading conditions

Next Steps

- If settlement issues are identified:
 - Record location, depth, and extent of settlement
 - Crest depression, shoulder slump, loss of freeboard, etc.
 - Uniform or differential settlement
 - Increase monitoring by adding survey monuments or settlement plates
 - Monitor for cracks, seepage and/or slope deformation
 - Lower reservoir level to reduce loading on the dam
 - Contain rapid drawdown
 - Engineers should perform settlement analysis and recommend an action plan

Next Steps

- If liquefaction issues are identified:
 - Record location, soil type, and liquefaction indicators
 - Sand boils, excessive pore pressure, sudden strength loss
 - Seismic loading (earthquake-induced) and static loading (high saturation)
 - Increase monitoring by adding piezometers to measure pore pressure
 - Monitor for settlement, cracking, or deformations
 - Lower reservoir level to reduce confining pressure and saturation
 - Contain rapid drawdown
 - Engineers should perform liquefaction potential analysis
 - Using CPT/SPT data and cyclic stress ratio methods
 - Seismic hazard assessment
 - Evaluate static liquefaction risk for saturated, or loose fills

Next Steps

- Develop Interim Risk Reduction Plan
- Develop and Revise Final Design Documentation for permit application to SCDES to correct all deficiencies (required if issued an Inspection and Repair Order by SCDES)
- Update Emergency Action Plan (EAP)

[Programs ▼](#)[Community ▼](#)[Business ▼](#)[Permits & Regulations ▼](#)[Data & Tools ▼](#)[About SCDES ▼](#)

Emergency Action Plans for Dams

[Home](#) > [Programs](#) > [Bureau of Water](#) > [Dams & Reservoirs](#) > [Emergency Action Plans for Dams](#)



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Resources



Resources

■ South Carolina Department of Environmental Services (SCDES)

- Dams and Reservoirs Safety Program



■ Federal Emergency Management Agency (FEMA)

- Dam Safety Guidelines



■ U.S. Army Corps of Engineers (USACE)

- Dam Safety Inspection Manual



■ Association of State Dam Safety Officials (ASDSO)

- Technical Manuals and Guidelines



■ American Society of Civil Engineers (ASCE)

- Dam Safety and Investigation Publications

