Workshop 2

Study of structural and foundation systems of Wind Turbines

Site Investigations and Field Testing

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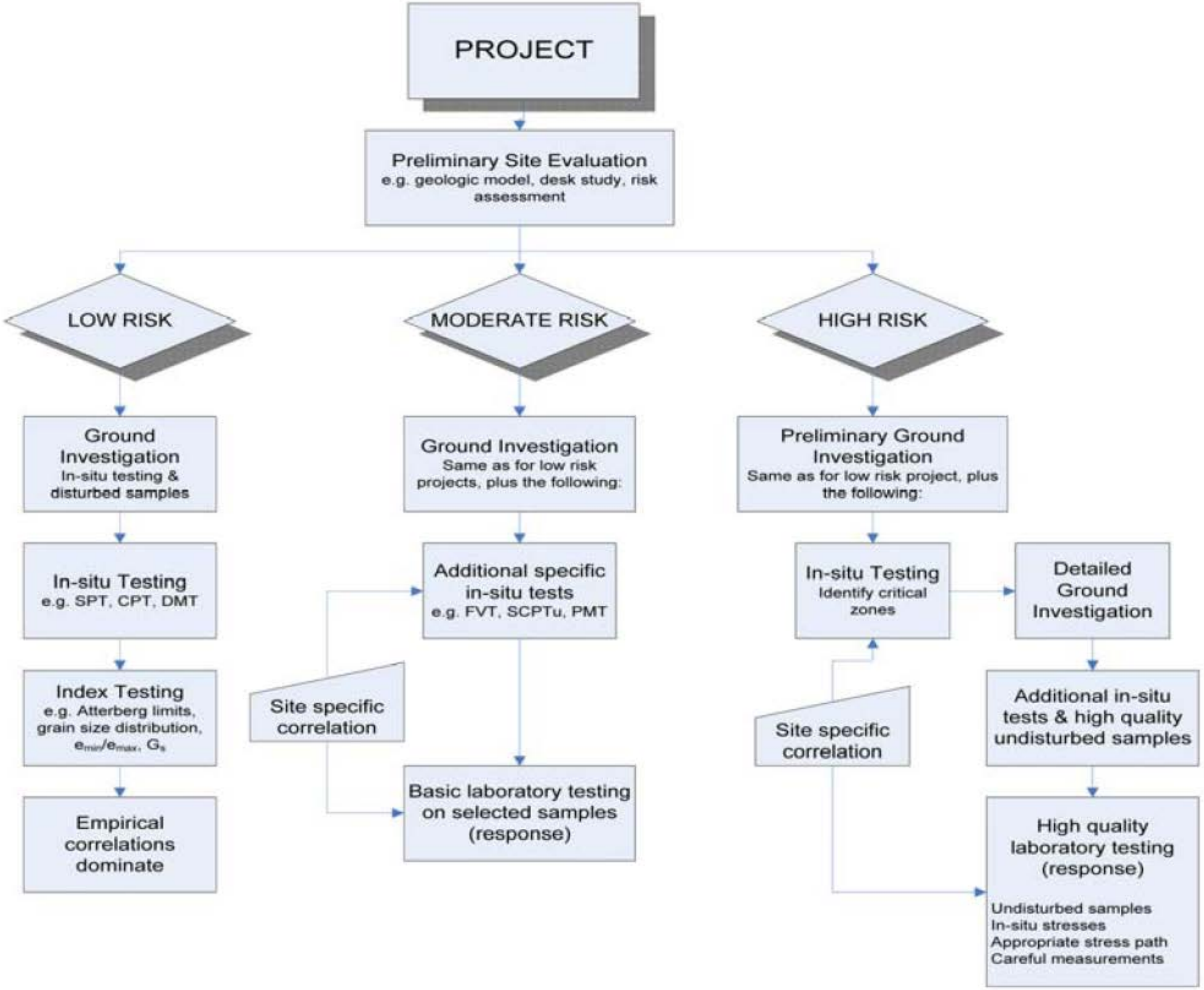


Risk Based Design of Exploration program

Risk and uncertainty are characteristics of the ground and are never fully eliminated. The appropriate level of sophistication for site characterization and analyses should be based on the following criteria:

- Precedent and local experience
- Design objectives
- Level of geotechnical risk
- Potential cost savings

The evaluation of geotechnical risk is dependent on hazards, probability of occurrence and the consequences. Projects can be classified as either low, moderate or high risk, depending on the above criteria.

The flow chart illustrates the likely geotechnical ground investigation approach associated with risk. The level of sophistication in a site investigation is also a function of the project design objectives and the potential for cost savings.

Site Investigation and Field Testing

Exploration Program

Boring, Logging, Testing and Sampling

- SPT (strength, compressibility)
- MAAG (hydraulic conductivity)

Laboratory Testing

- Physical Properties
- Classification
- Strength & compressibility
- Non Linear soil behavior

Field Testing

Geophysical Methods

Seismic Methods Vs & Vp profiles

- MASW
- Crosshole, Downhohe
- P-wave Refraction

Electrical Resistivity Tomography

- Stratigraphy & Voids
- Electrical Engineering

Microgravity

Voids

Other in-situ methods

- CPT (classification, strength & compressibility, liquefaction study
- PMT (strength & compressibility, piling design)

- **LOW RISK**
- **MODERATE RISK**
- **HIGH RISK**

(wind turbines)

DAILY

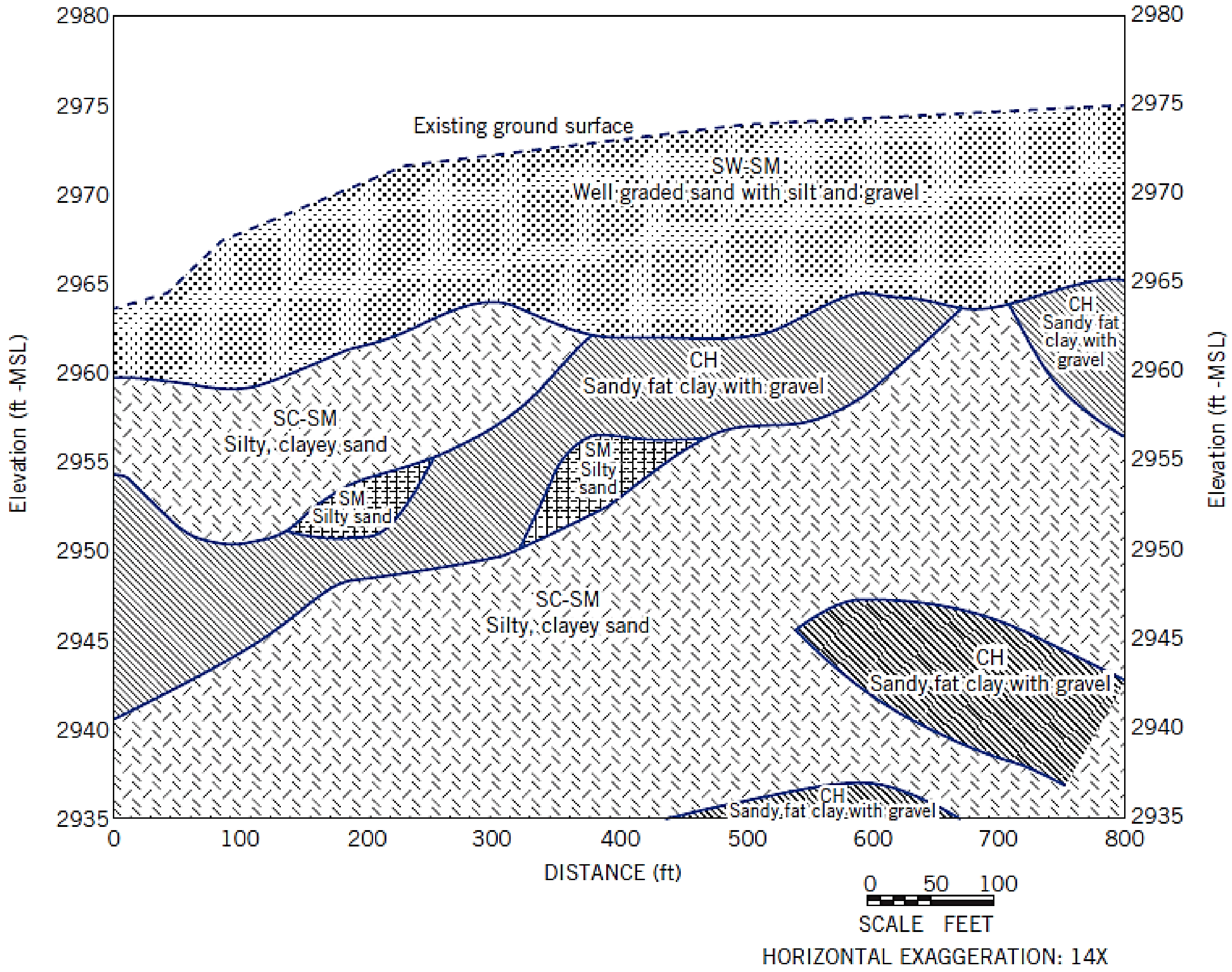
BOREHOLE RECORD WT4-B1

Borehole diameter: Φ117 – Φ101 Casing diameter: Φ117	Boring rig: Boyles-17 Ground elev.: +356,50m	Date: 6/9/2019 Weather: Αίθριος	Sheet No. 6 Sheet No. per borehole 1

Casing Diameter	Casing Depth	Depth from ground level	Drilling From	Drilling To	Sample No.	Type of sample Disturb.	Undist.	S.P.T. No. of blows	Sample description	Ground water level Time	Ground water level Level	Remarks
Φ117	0.00–1.50		0.00	0.30	–	Φ			[illegible]			Διάτρηση W117: 0.00 – 1.50 KΦ101: 1.50 – 5.50 W101: 5.50 – 15.50 KΦ101: 15.50 – 20.00 W101: 20.00 – 30.00
		1.00	0.30	0.90	Δ1	Φ			[illegible] (Δ1)			
			0.90	1.50	Δ2	Φ			[illegible] (Δ2)			
		2.00	1.50	3.00	–	Y			[illegible] (I–II) [illegible] A:100% RQD: 50/150			
		3.00	3.00	4.00	–	Y			[illegible] (I–II) A:100% RQD: 50/100			
		4.00	4.00	5.50	–	Y			[illegible] (II–III) A: 130/150 RQD: 0%			[illegible] H₂O στα 4.00m
		5.00										
		6.00	5.50	6.80	03	Φ			[illegible]			X: 436,223 m Y: 4275,181 m

FOR THE CLIENT

- ☒ Disturbed sample
- ◪ Undisturbed sample
- Φ Dry sampling
- Y Wet sampling
- ○ Sample not recovered

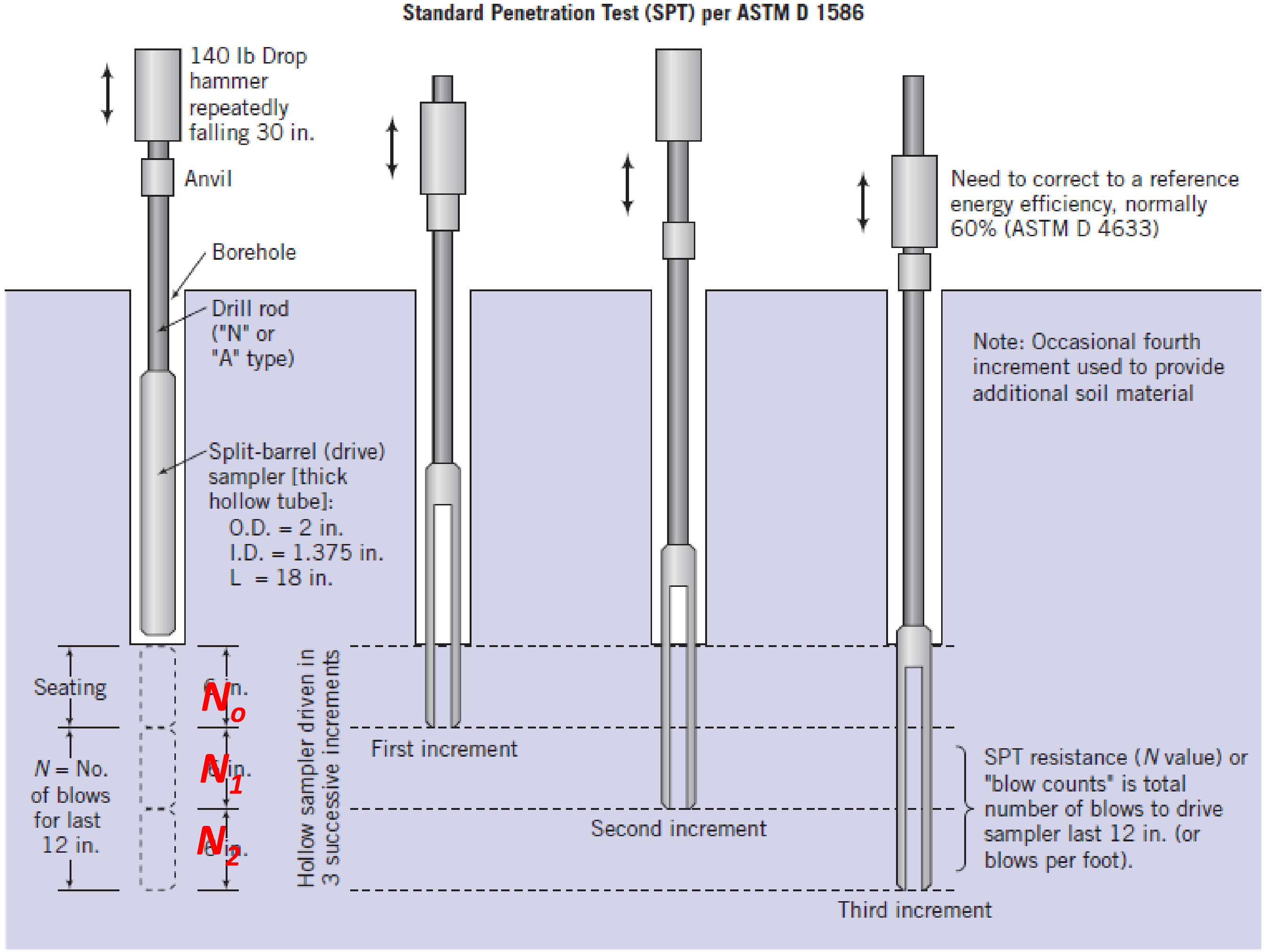


Scope of Exploration program

1. **Construction of Soil Section**
2. **Identification of soil/rock layers**
3. **Assign physical, mechanical and dynamic parameters to the soil/rock layers**

INPUT FOR THE DESIGN STUDIES

Site Investigation and Field Testing



$N_{SPT}=N_1+N_2$ blows for 30cm penetration

Standard Penetration Test (SPT)

The standard penetration test (SPT) it is perhaps the most popular field test. The SPT is performed by driving a standard split-spoon sampler into the ground by blows from a drop hammer of mass 63.5kg falling from 760mm height.

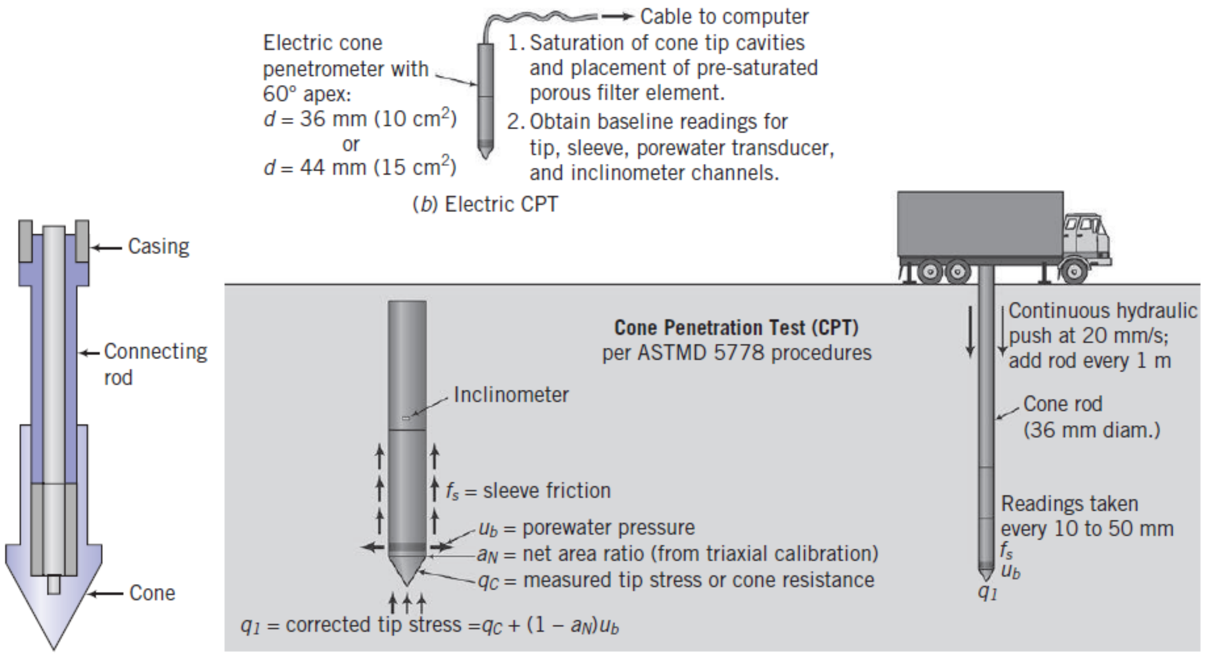
Many widely published international correlations which relate blow count, or N-value, to the engineering properties of soils are available for geotechnical engineering purposes.

The sampler is driven 150 mm into the soil at the bottom of a borehole, and the number of blows (N) required to drive it an additional 300mm is counted. The number of blows (N) is called the standard penetration number.

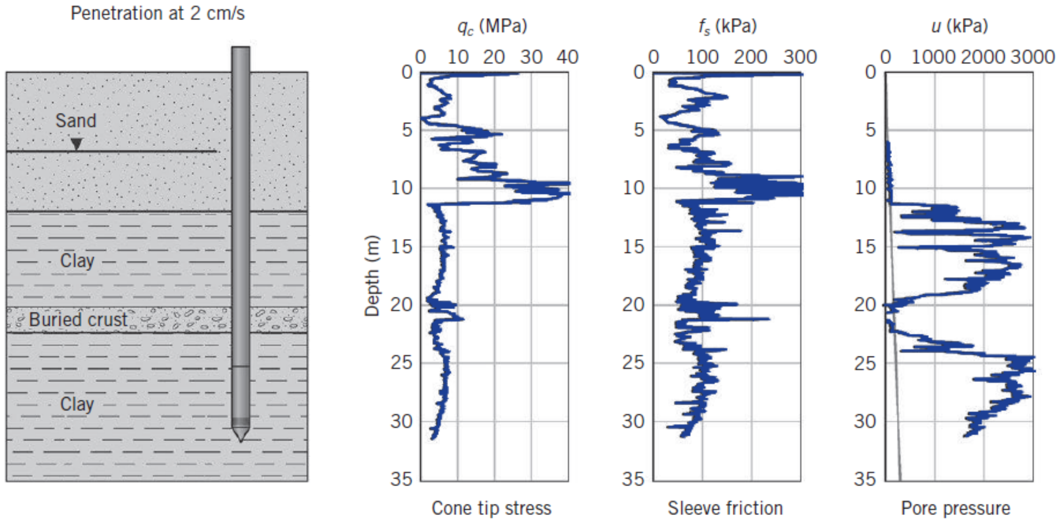
For very dense coarse grained soils or when an obstacle is encountered, the number of blows may exceed 50. When this occurs, the SPT record would read “refusal.” In practice, SPT are usually conducted at 1.5-2.0m intervals.

Various corrections are applied to the N values to account for energy losses, overburden pressure, rod length, and so on. It is customary to correct the N values to a rod energy ratio of 60%. The rod energy ratio is the ratio of the energy delivered to the split spoon sampler to the free-falling energy of the hammer. The corrected N values are denoted as N60

Cone Penetration Test (CPT)



(a) CPT (c) Piezocone (d) CPT field set up.

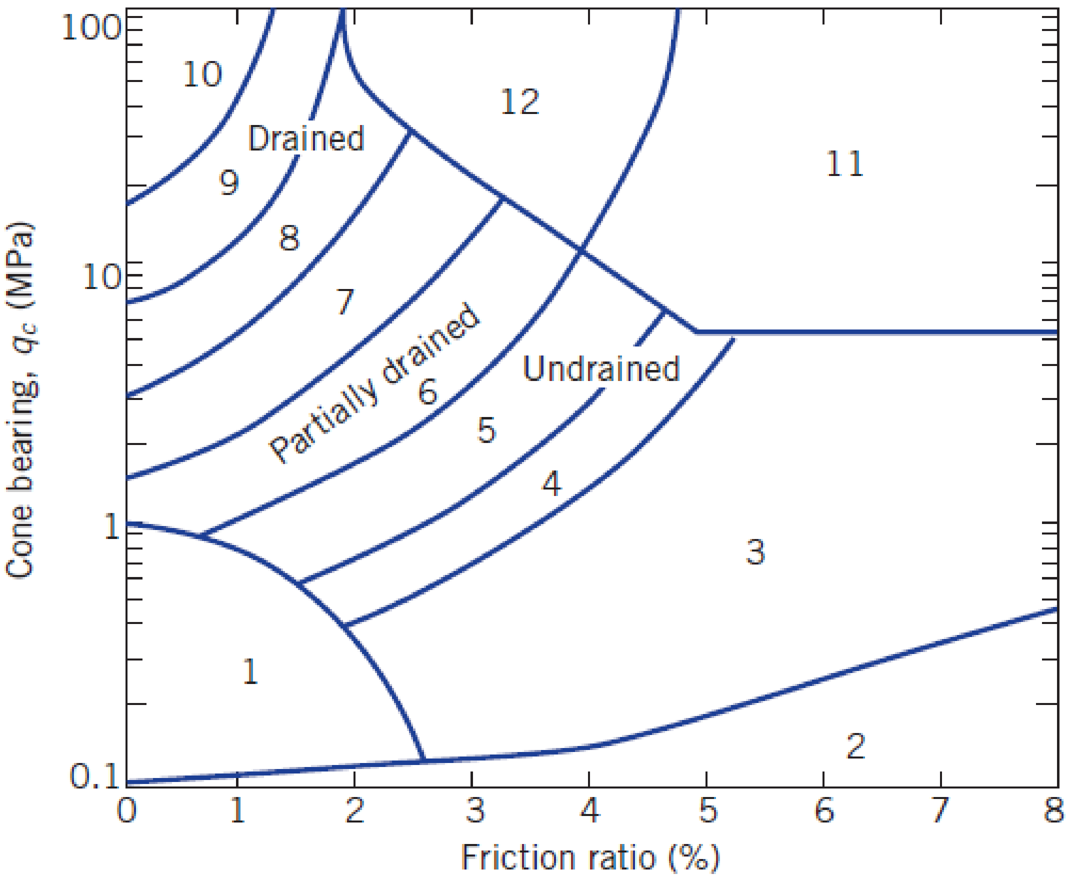


The cone penetrometer is a probe that is attached to a rod. An outer sleeve of surface area encloses the rod just above the cone base. The thrusts required to drive the cone and the sleeve into the ground at a rate 2 cm/s are measured independently so that the end resistance or cone tip resistance, q_c, and side friction or sleeve resistance, f_s, may be estimated separately. The friction ratio, $R_f = 100 x f_s/q_c$ is often used to present the sleeve resistance. Although originally developed for the design of piles, the cone penetrometer has also been used to estimate the bearing capacity and settlement of all types of foundations.

The piezocone (uCPT or CPTu) is an electric cone penetrometer that has porous elements inserted into the cone or sleeve to allow for porewater pressure measurements. The piezocone is a very useful tool for soil profiling. The piezocone provides useful data to estimate the shear strength, bearing capacity, and consolidation characteristics of soils.

The CPT is applicable only in loose and soft soil layers and provides extremely useful data for **liquefaction studies.**

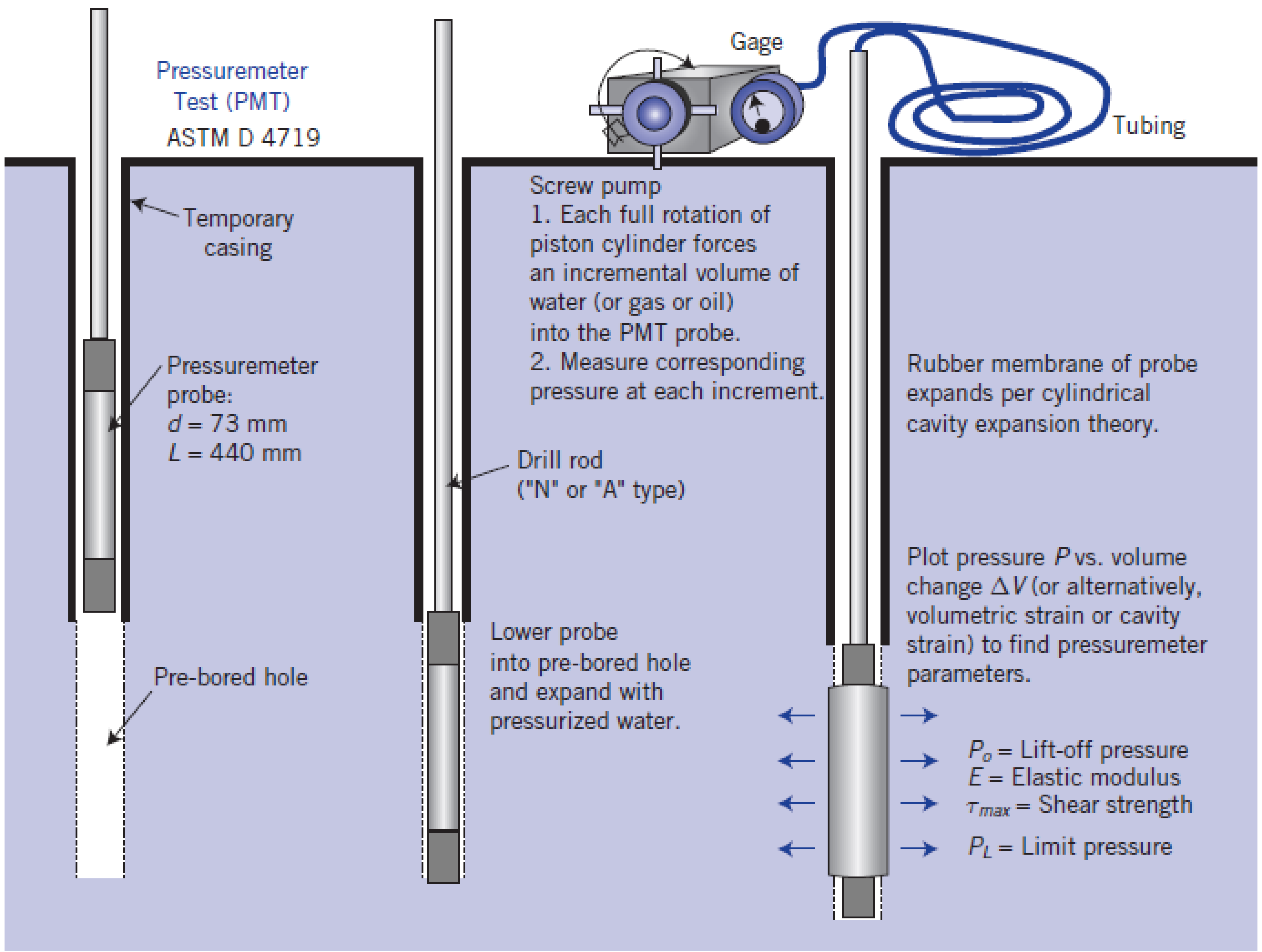
Cone Penetration Test (CPT)



ZONE	SOIL BEHAVIOR TYPE
1	Sensitive fine-grained
2	Organic material
3	Clay
4	Silty clay to clay
5	Clayey silt to silty clay
6	Sandy silt to clayey silt
7	Silty sand sandy silt
8	Sand to silty sand
9	Sand
10	Gravelly sand to sand
11	Very stiff fine-grained (*)
12	Sand to clayey sand (*)

(*) overconsolidated or cemented

Source: Modified from Robertson, 1990



Pressuremeter: ASTM D 4719-87

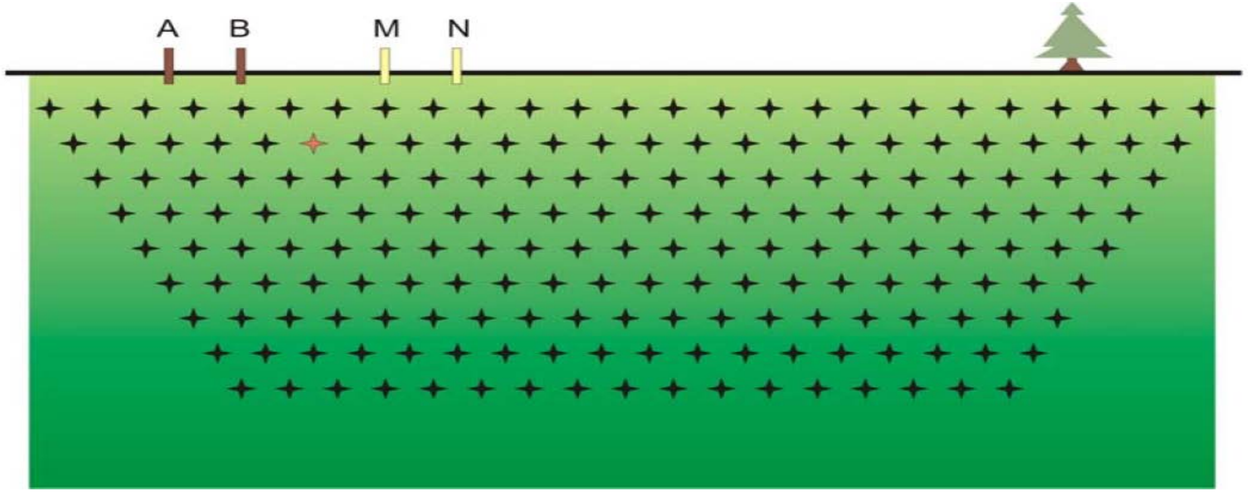
The Menard pressuremeter is a probe that is placed at the desired depth in an unlined borehole, and pressure is applied to a measuring cell of the probe.

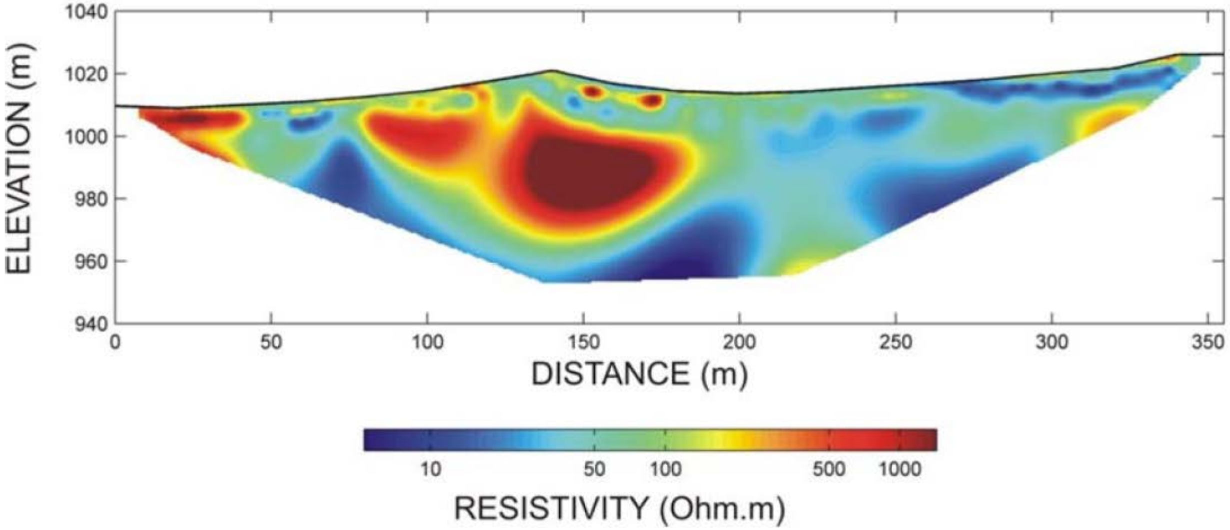
The pressure applied is analogous to the expansion of a cylindrical cavity. The pressure is raised in stages at constant time intervals, and volume changes are recorded at each stage.

A pressure–volume change curve is then drawn from which the elastic modulus, shear modulus, horizontal stress, friction angle and undrained shear strength may be estimated.

The pressuremeter test is more costly than CPT and is not widely available. The drainage condition is unknown, and this leads to uncertainty in the interpretation of the test data to estimate the shear modulus and shear strength.

Electrical Resistivity Tomography (ERT)



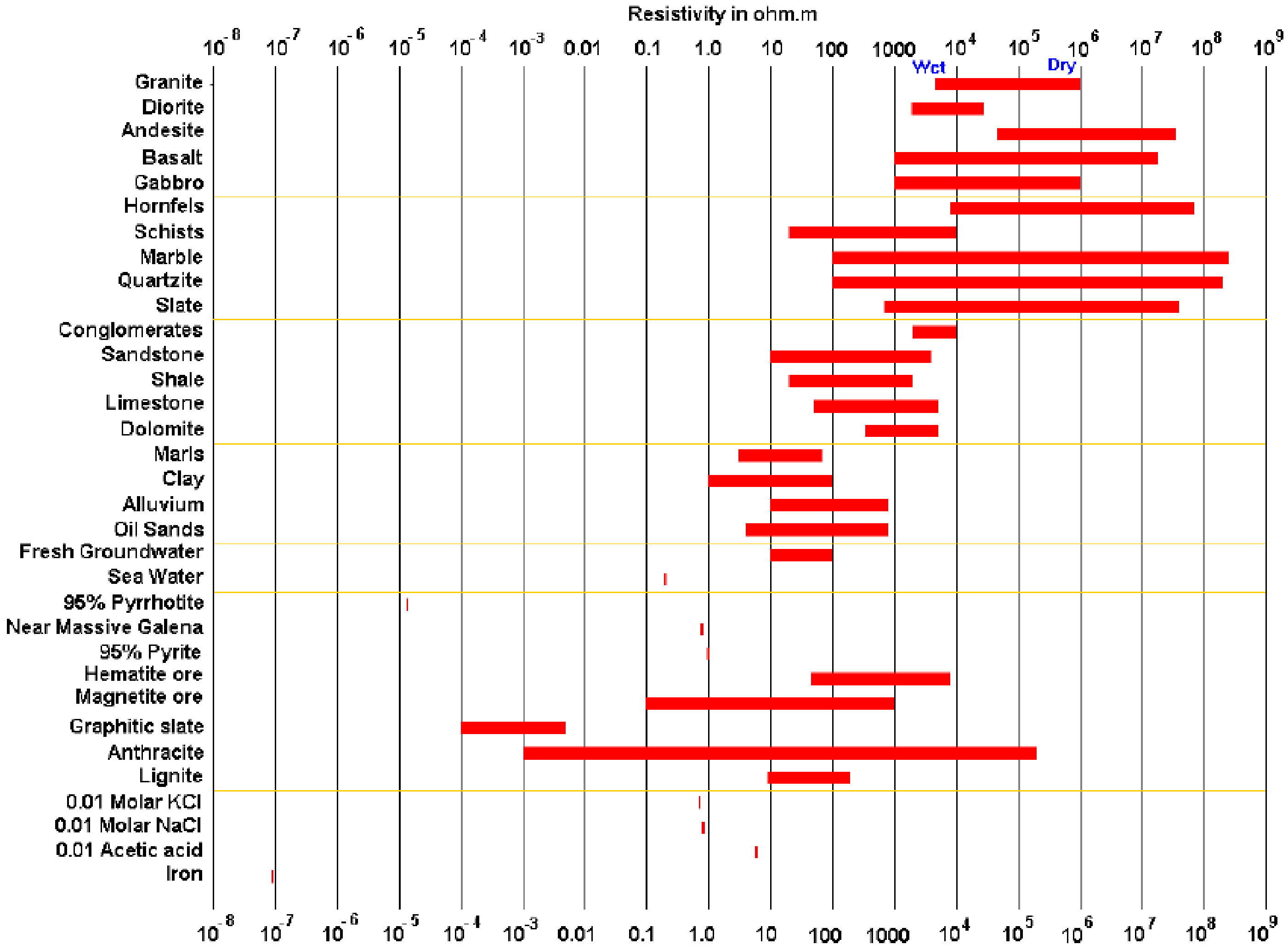


The electrical resistivity tomography method is used to determine the distribution of electrical resistivity in the subsurface. It uses an artificial source of commuted direct current which is usually introduced into the ground via two-point electrodes (metal rods A and B. By doing this, a potential distribution is established in the subsurface depending on the resistivity distribution in the ground. Two potential electrodes (M and N) can be used to measure the potential difference between two selected points on the surface. Knowing this voltage difference, the introduced current and the position of all four electrodes, an apparent resistivity can be calculated.

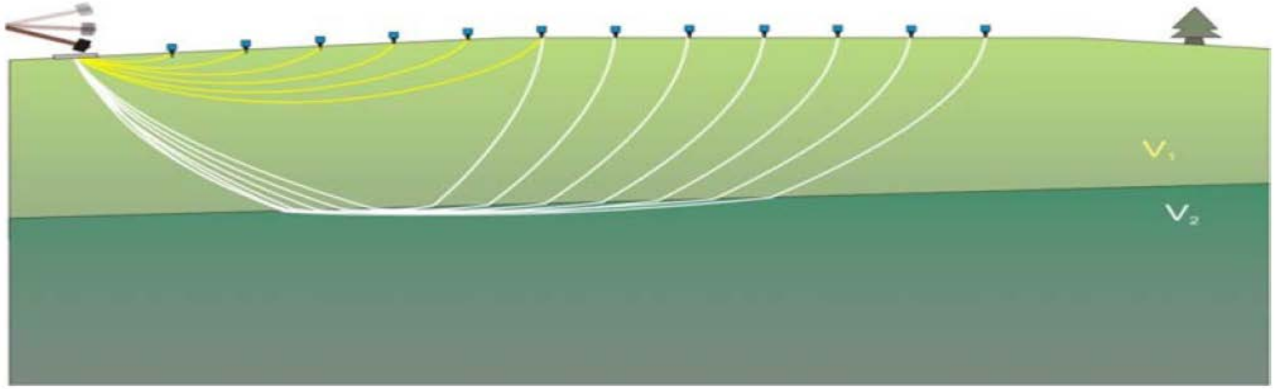
To optimize the acquisition many electrodes are introduced simultaneously in the ground. A resistivity-meter automatically selects combinations of four electrodes to create a quasihomogeneous distribution of measurements beneath the surface. When all the data points have been collected, an iterative inversion algorithm creates models of the subsurface by fitting the observed data with predicted ones. When the comparison is good enough, the iterative process is stopped. In this way a resistivity model of the study area can be constructed.

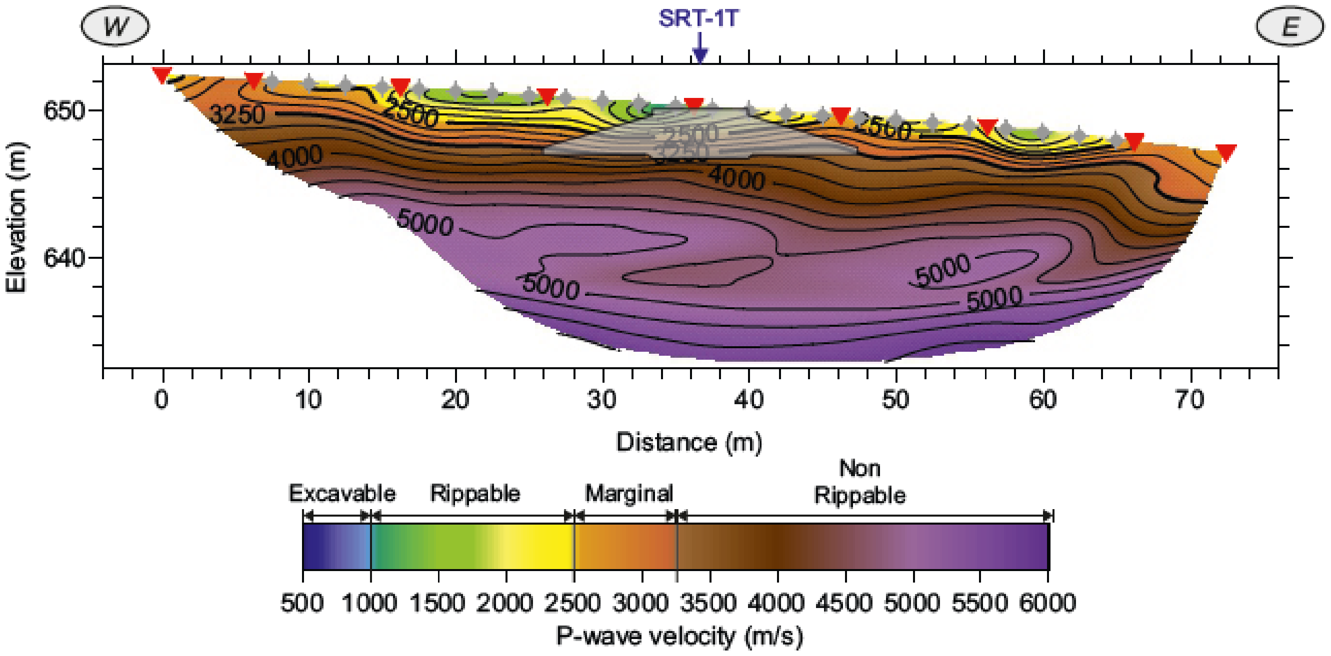
There are several factors influencing the values of electrical resistivity as the moisture content, presence of pollutants and porosity.

Electrical Resistivity Tomography (ERT)



Seismic Refraction Tomography (SRT)





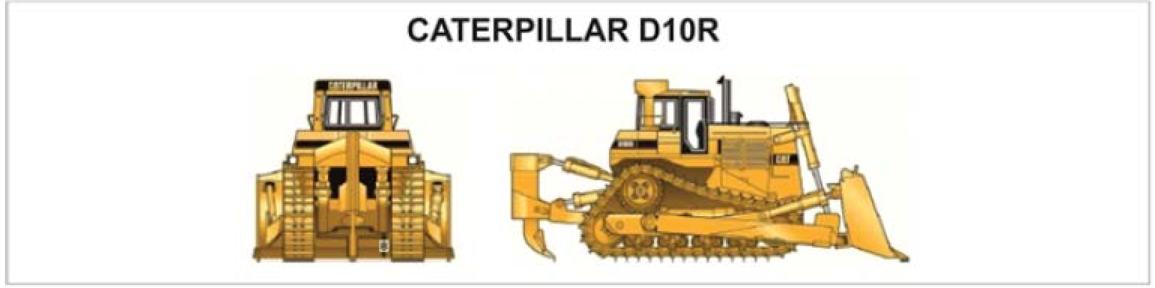
The seismic refraction tomography is considered as an evolution of the traditional seismic refraction, and it's based in the generations of mechanic perturbation in the soil (usually made with a hammer), and calculating the time that **P waves** takes to travel the distance between the source and a series of sensors (geophones) placed along an acquisition seismic line. Knowing the distance traveled by the P wave and the time used, it's possible to calculate the seismic wave propagations velocity in the subsurface.

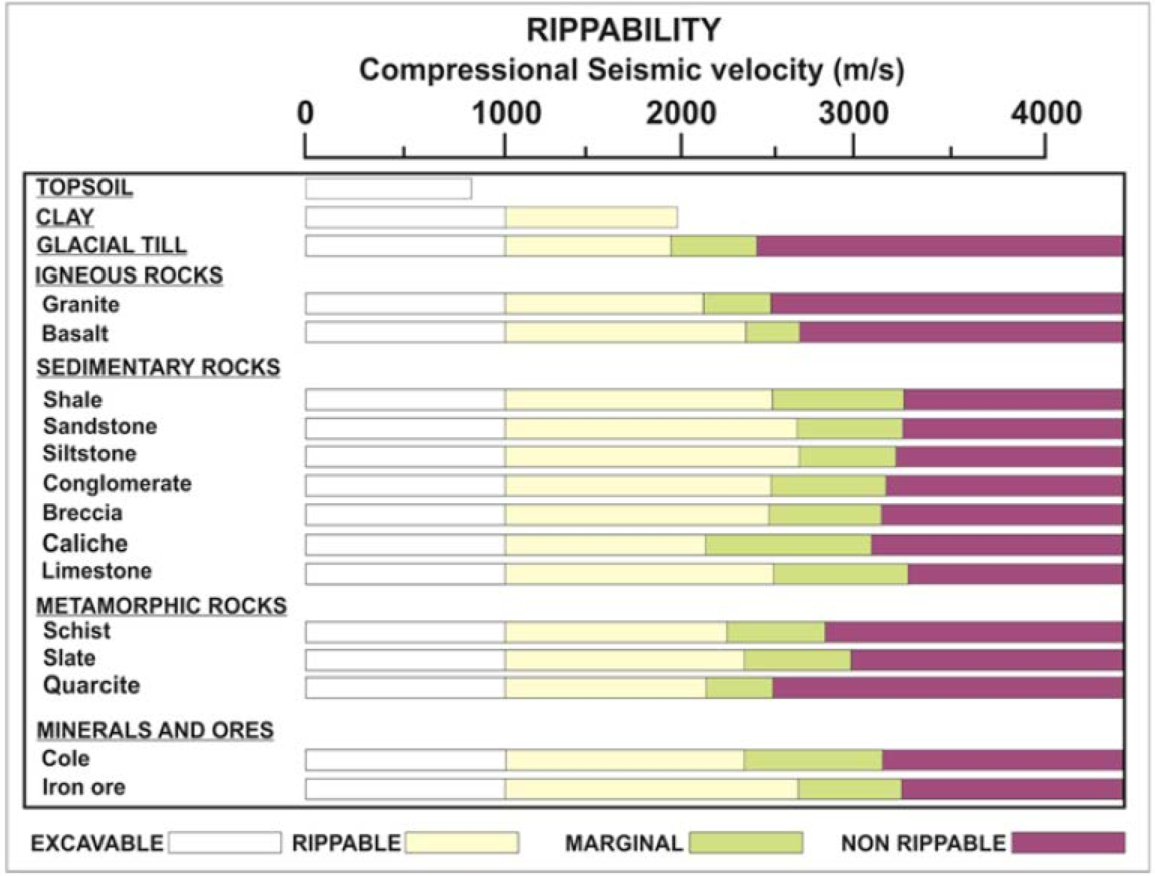
One of the most important aspects of the seismic tomography is that it is a method based on "residue" inversion. The difference between observed seismic travel times and theoretical travel times is called "residue". Therefore, it is very important to use a processing tool that is able to accurately reproduce the seismic waves travel times in a complex medium.

It is possible to reproduce very precisely the path followed by the P wave from the source to the receiver. The inversion process will lead to the final model is an iterative process, where the initial model is updated in each iteration to give the final model.

SRT provide useful information regarding soil stratigraphy, excavatability and rippability.

Seismic Refraction Tomography (SRT)

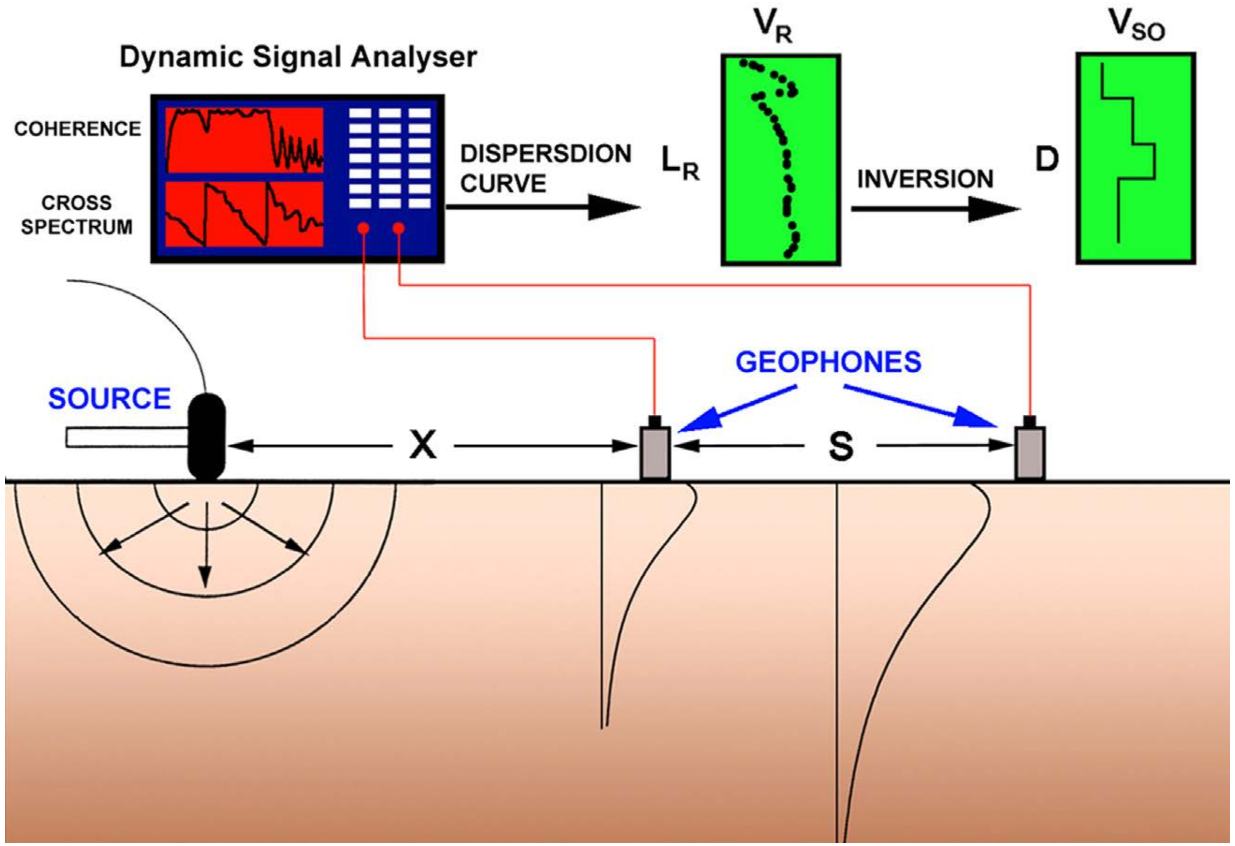


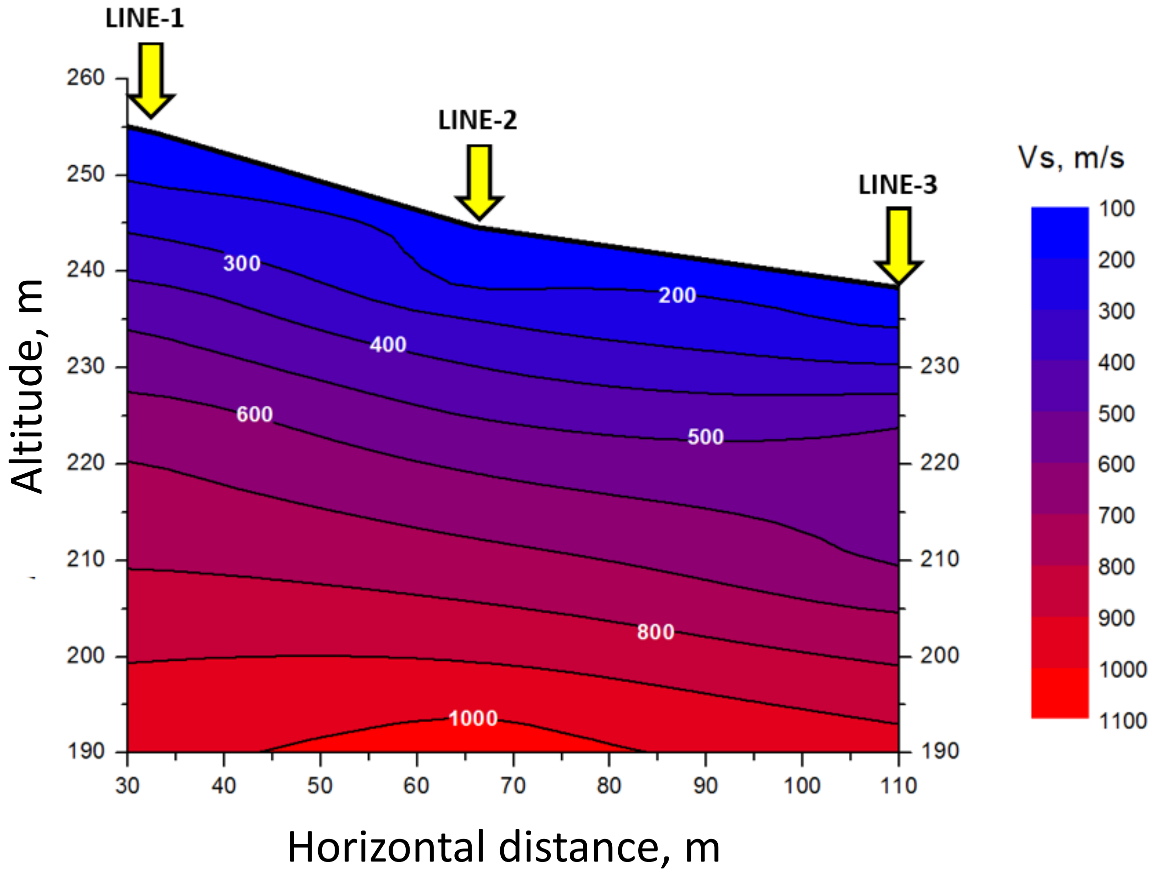


Rippability chart based on D-10R Caterpillar machine

(Geotechnical Engineering Techniques and Practices, Hunt, Roy E., McGraw-Hill Book Company, 1986).

Surface Wave Methods: SASW, MASW, SWEPT SINE

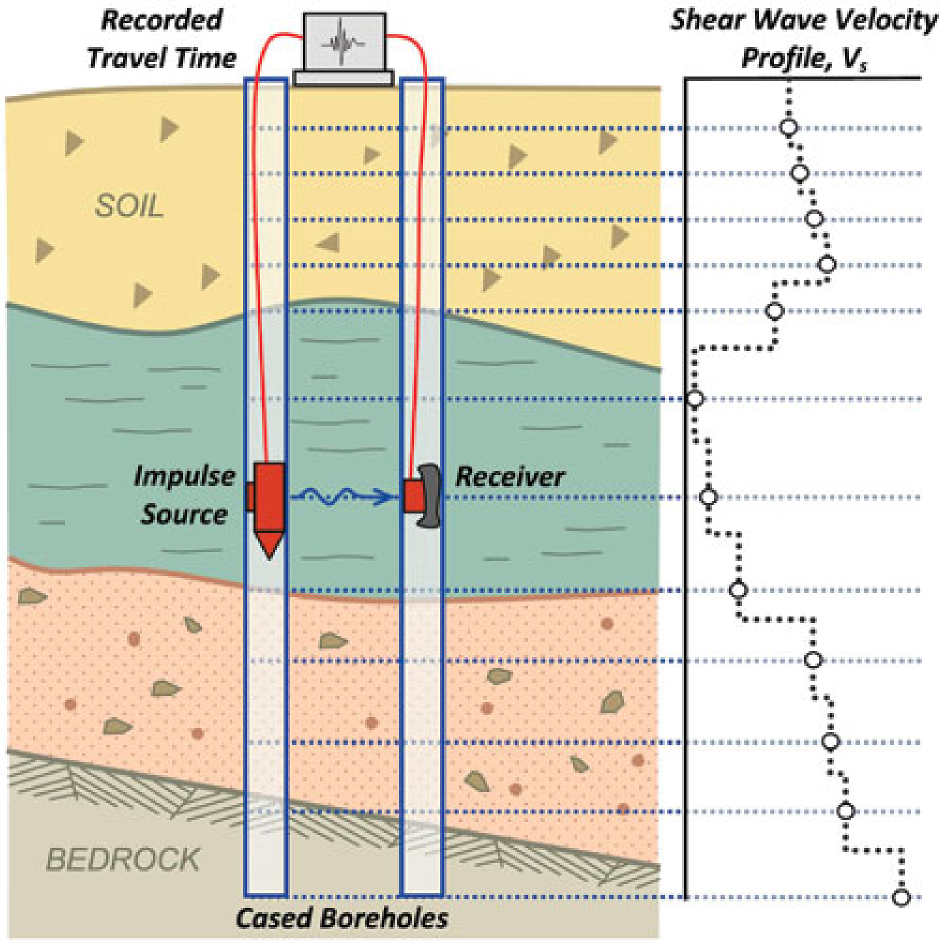




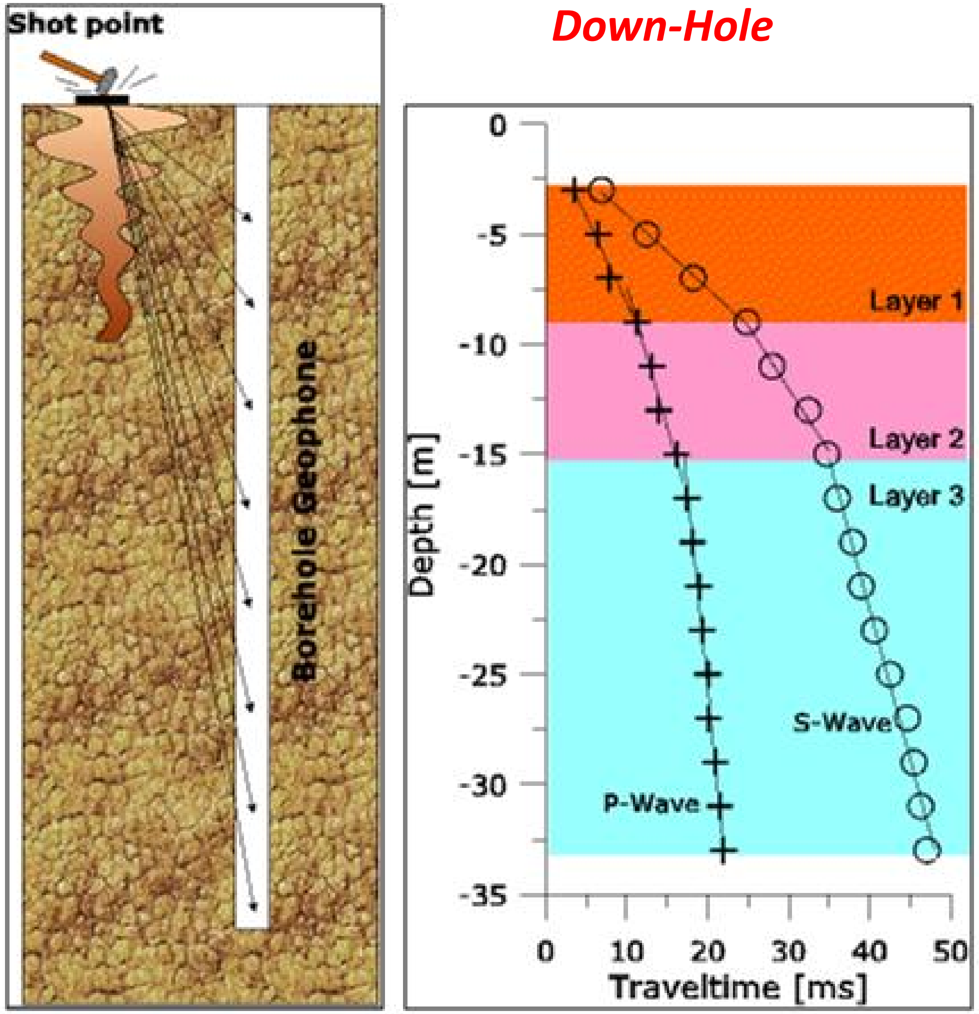
$$G_{max}=\rho V_s^2$$

Site Investigation and Field Testing

Cross-Hole



Down-Hole



Ground type	Description of stratigraphic profile	Parameters		
		$v_{s,30}$ (m/s)	N_{SPT} (blows/30cm)	c_u (kPa)
A	Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface.	> 800	–	–
B	Deposits of very dense sand, gravel, or very stiff clay, at least several tens of metres in thickness, characterised by a gradual increase of mechanical properties with depth.	360 – 800	> 50	> 250
C	Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres.	180 – 360	15 - 50	70 - 250
D	Deposits of loose-to-medium cohesionless soil (with or without some soft cohesive layers), or of predominantly soft-to-firm cohesive soil.	< 180	< 15	< 70
E	A soil profile consisting of a surface alluvium layer with v_s values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with v_s > 800 m/s.			
S_1	Deposits consisting, or containing a layer at least 10 m thick, of soft clays/silts with a high plasticity index (PI > 40) and high water content	< 100 (indicative)	–	10 - 20
S_2	Deposits of liquefiable soils, of sensitive clays, or any other soil profile not included in types A – E or S_1			

Vs profiles are important for:

- ***the soil categorization based on EC8***
- ***Seismic response analyses***

Laboratory Testing

→ **Physical Properties & Classification**: Unit weight, water content, plasticity, grain size

→ **Strength & compressibility**: Unconfined or **Triaxial compression test**, Direct shear test
Consolidation test

→ **Dynamic properties & non linear behavior**: **Resonant column test, γ<10^{-3}**

Cyclic Triaxial test

- **LOW RISK**
- **MODERATE RISK**
- **HIGH RISK**

(wind turbines)

Thank you for your attention