



PANAMGEO CHILE 2024

XVII CONGRESO PANAMERICANO
DE MECÁNICA DE SUELOS E INGENIERÍA GEOTÉCNICA

2ª CONFERENCIA REGIONAL
LATINOAMERICANA DE IAEG

Investigation and analysis of the seismic stability of mine waste and tailings

ROBB MOSS

RICARDO MOFFAT



CAL POLY



OPERACIONES DE LA GRAN MINERÍA DE CHILE

I Region

Quebrada Blanca; Teck
Doña Inés de
Collahuasi,
Glencore, Anglo
American, JCR
Cerro Colorado;
Atalaya Mining plc

II Region

Alto Norte;
Glencore, Xstrata
Antucoya,
Antofagasta
Minerals,
Marubeni
Centinela,
Antofagasta
Minerals,
Marubeni
Chuquicamata, Codelco Chile
El Abra; Cyprus,
Codelco Chile
Escondida; BHP
Billiton, Rio Tinto, JECO Corp.
Francke; Minera Las Cenizas
Gabriela
Mistral, Codelco Chile
Lomas Bayas; Glencore
Ministro Hales, Codelco Chile
RadomiroTomic, Codelco Chile
Sierra Gorda,
KGHM Polska
Miedz S. A.,
Sumitomo
Metal Mining,
Sumitomo
Corporation
Spence, BHP
Billiton
Zaldivar, Barrick Gold

III Region

Candelaria,
Lundin Mining
Corp.,
Sumitomo Corp.
Ojos del Salado, Lundin Mininbg
Corp.
Caserones,
Lumina Copper Chile
Salvador, Codelco Chile

V Region

Andina, Codelco Chile
El Soldado,
Anglo American Chile
Ventanas, Codelco Chile
Chagres, Anglo
American,
Codelco-
Mitsui,
Mitsubishi Corp.

VI Region

El Teniente, Codelco Chile

IV Region

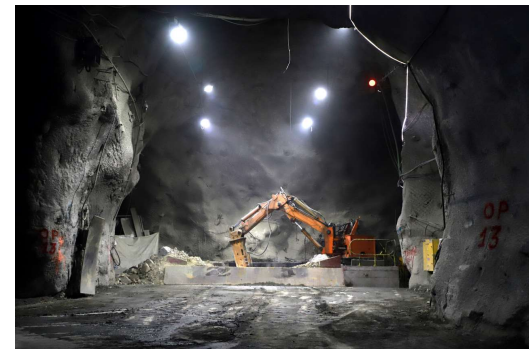
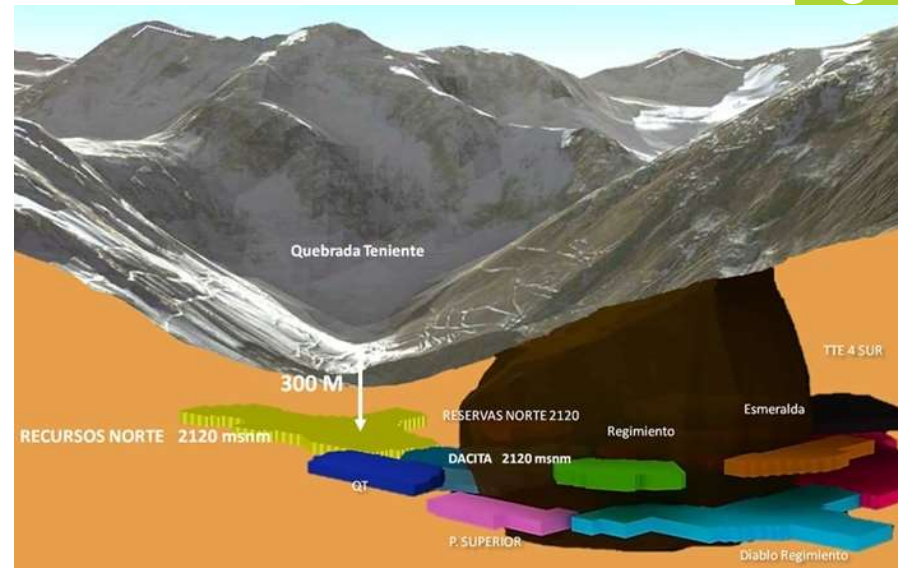
Carmen de
Andacollo, Teck, Enami
Los Pelambres,
Antofagasta
Minerals,
Nippon Mining,
Mitsubishi
Materials,
Mitsubishi Corp.

Metropolitana

Los Bronces,
Anglo American Chile



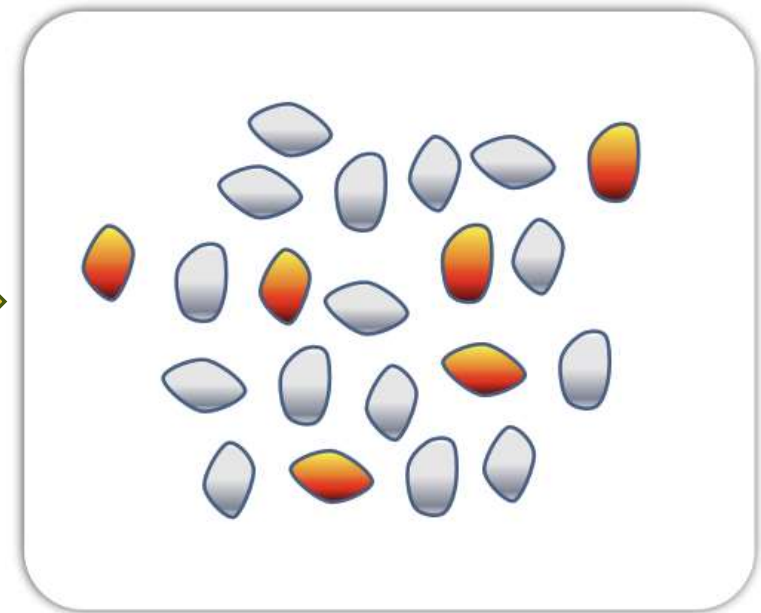
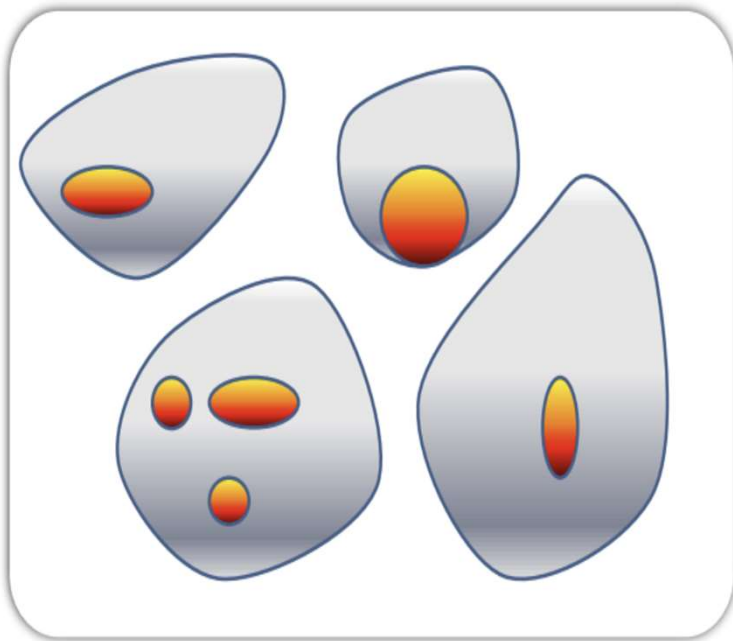
OPERACIONES MINERIA RAJO ABIERTO y SUBTERRÁNEA

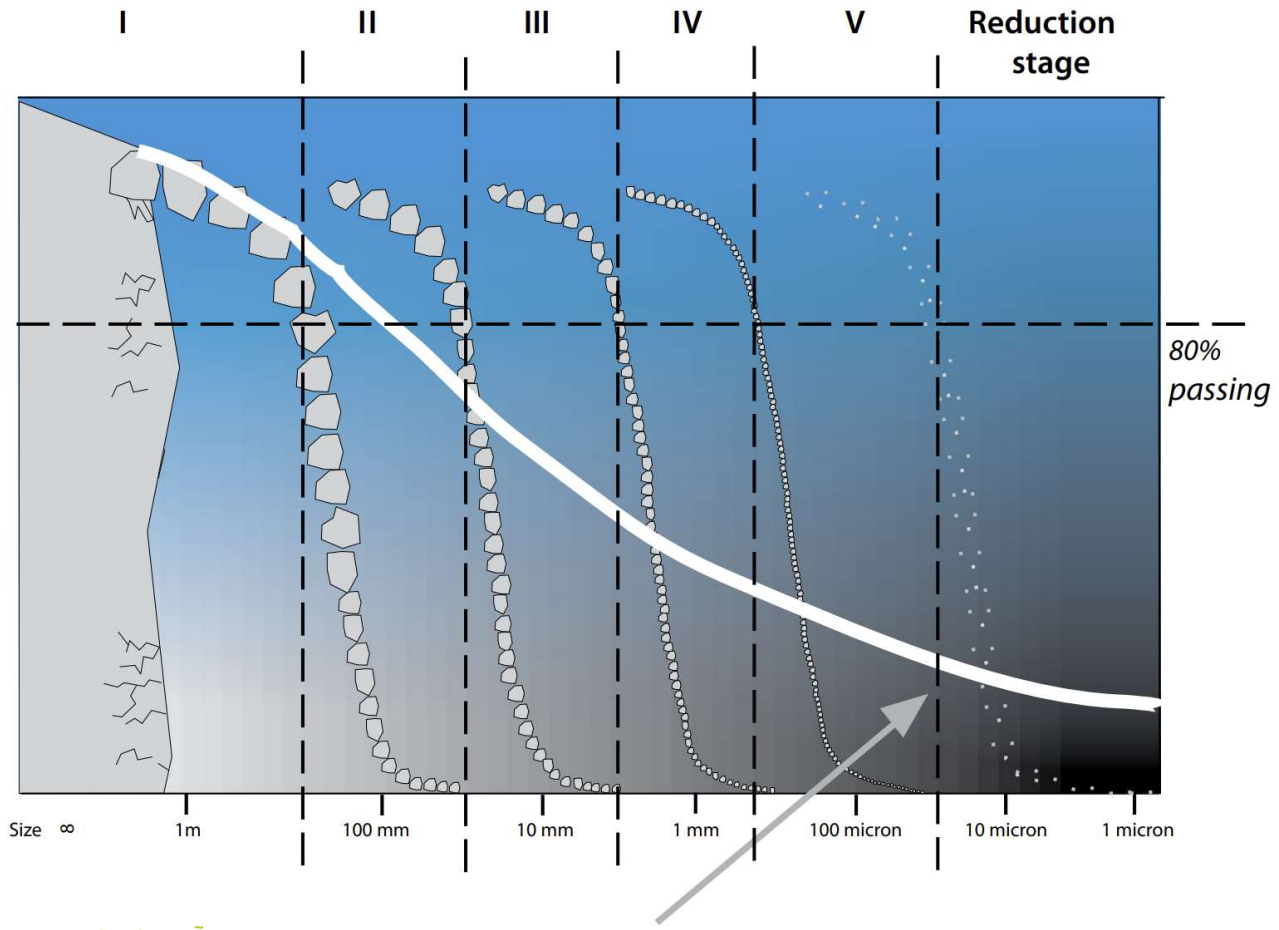


OPERACIONES MINERIA RAJO ABIERTO y SUBTERRÁNEA



Tranques de relaves





Tranques de relaves

Activos: **106**
Inactivos: **463**
Abandonados: **173**
Total Nacional: **742**



I Región: 7
II Región: 51
III Región: 161
IV Región: 385
V Región: 78
RM: 26
VI Región: 19
VII Región: 6
XI Región: 9



Tranques de Relaves

Tranque Ovejería División Andina Codelco Chile

FACULTAD DE
INGENIERÍA Y CIENCIAS



Tranque Ovejería

RELAVES MINEROS UNIVERSIDAD ADOLFO IBÁÑEZ
26-11-2024



Tranques de Relaves Tranque Las Tórtolas, AngloAmerican

FACULTAD DE INGENIERÍA Y CIENCIAS



Tranque Las Tórtolas



Tranque Ovejera

Tranque Las Tórtolas

RELAVES MINEROS UNIVERSIDAD ADOLFO IBÁÑEZ
26-11-2024

Site investigation

- ▶ What am I looking for?
 - ▶ Undrained strength, Drained strength, pore water distribution, liquefaction assessment, saturation. Hydraulic conductivity, stiffness others

Exploration Pit



Exploration drilling



Rotary (Wash) Borings/ Drilling

- The drilling bit is pushed by the equipment while rotating.
- Perforation walls can be hold by drilling fluids or casing.

Diamond core drilling bits



Casing



Drilling bits



Descarga del fluido



Shelby Tube

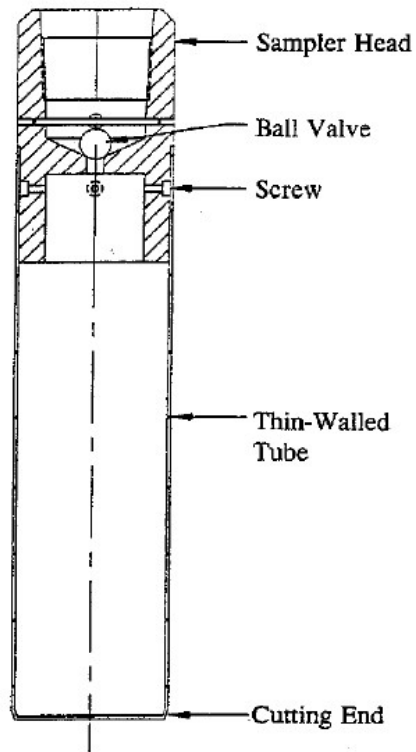


Figure 3-10: Schematic of Thin-Walled Shelby Tube (After ASTM D 4700).



Figure 3-11: Selected Sizes and Types of Thin-Walled Shelby Tubes.

Presiometer

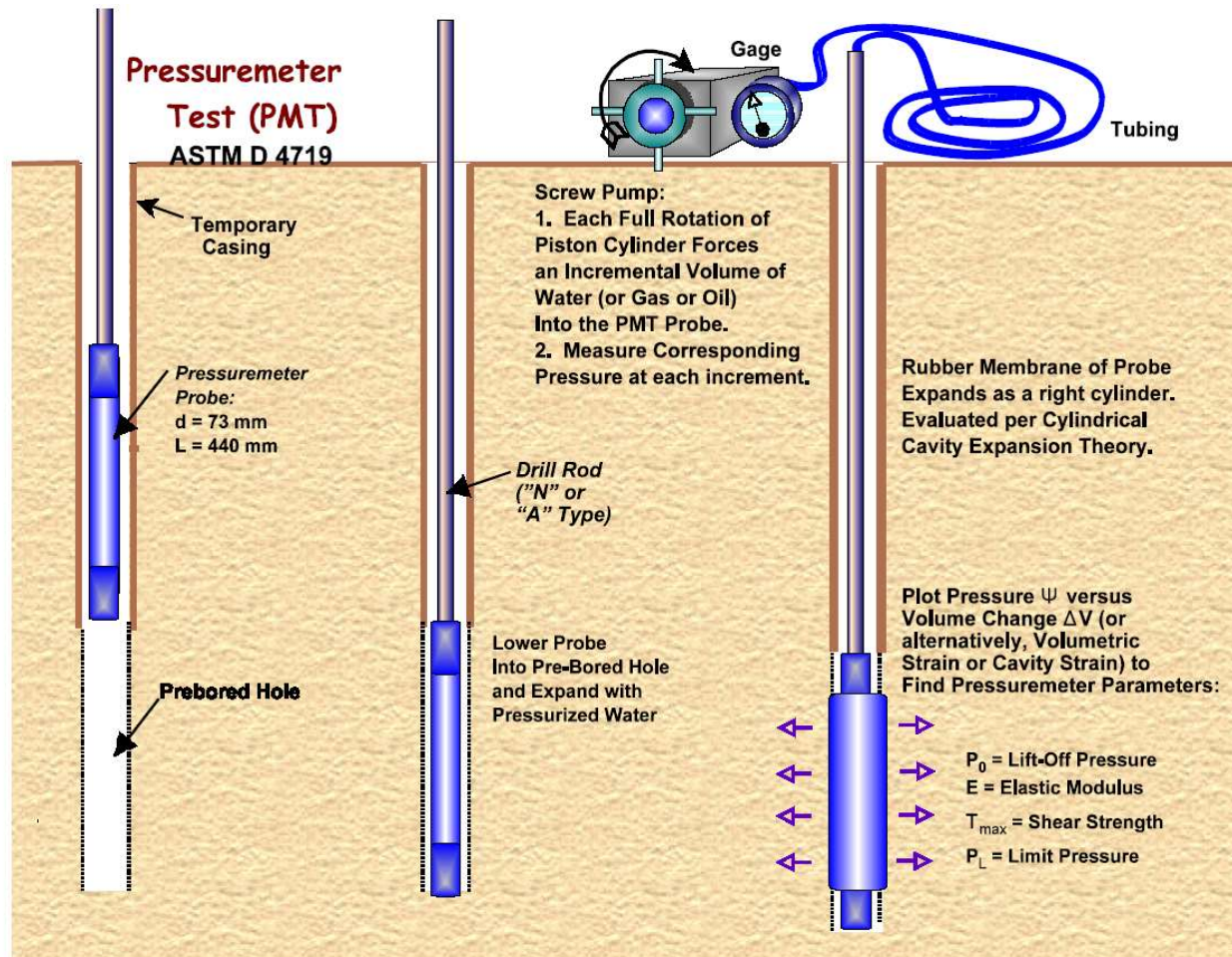


Figure 5-17. Test Procedure and Conduct of the Pre-Bored Type (Menard) Pressuremeter Test.



Figure 5.18. Photos of Pressuremeter Equipment, including Menard-type pressure panel, SBP probe, SBP cutter teeth, hydraulic jack, and monocell-type probe.

Ensayos de penetración (SPT)

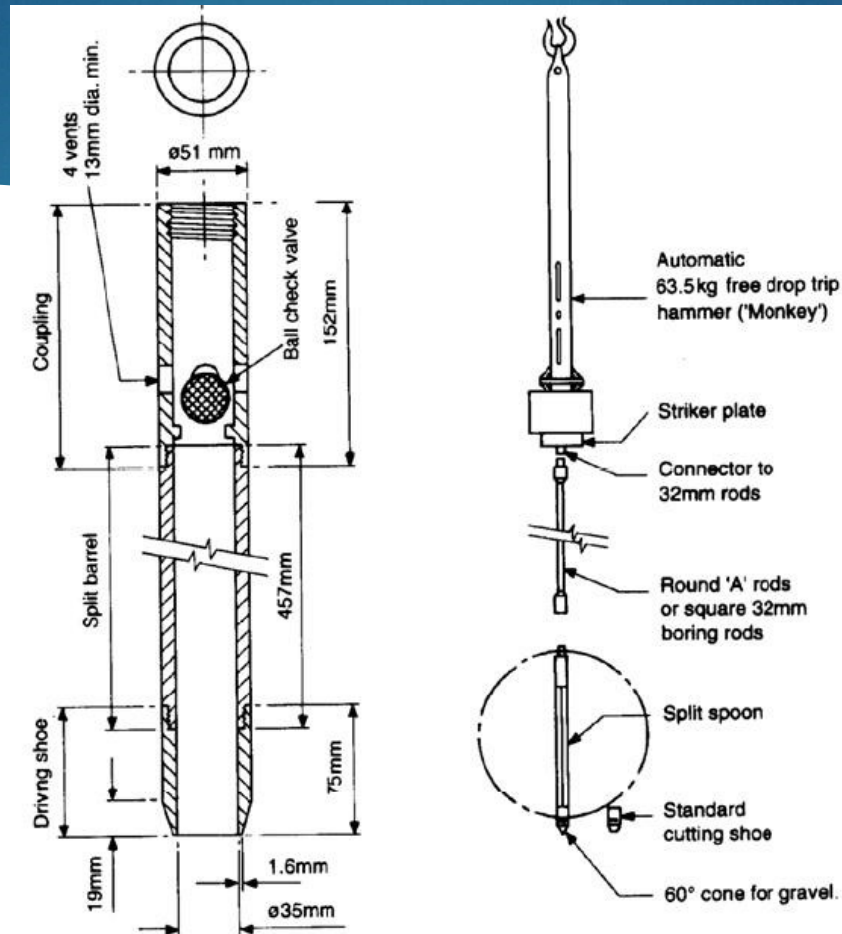
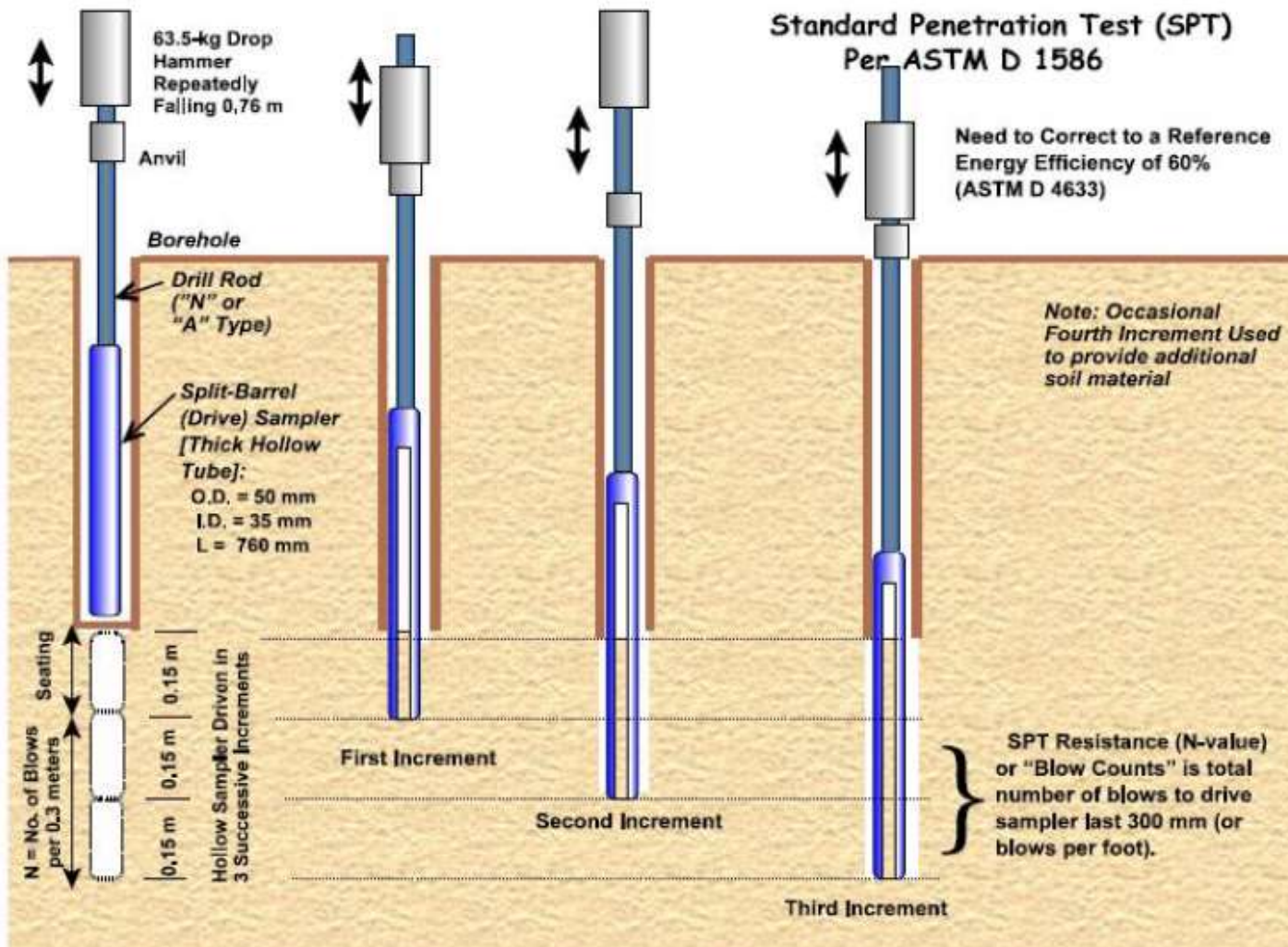
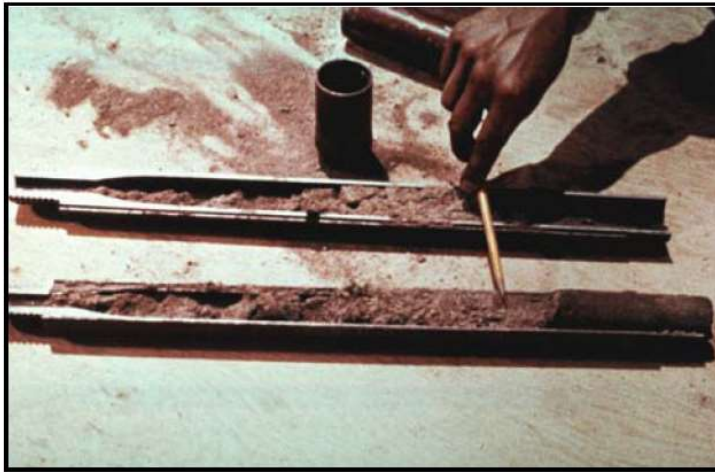


Fig. 9.1 Equipment for the standard penetration test.

STANDARD PENETRATION TESTING (SPT)





(a)



(b)

Figure 3-8: Split Barrel Sampler: (a) Open sampler with soil sample and cutting shoe; (b) Sample jar, split-spoon, shelby tube, and storage box for transport of jar samples.

SPT

Advantages

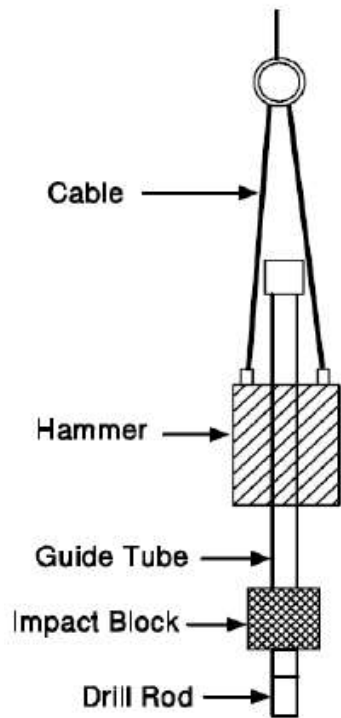
- ▶ Simple
- ▶ Good for sands and silts

Disadvantages

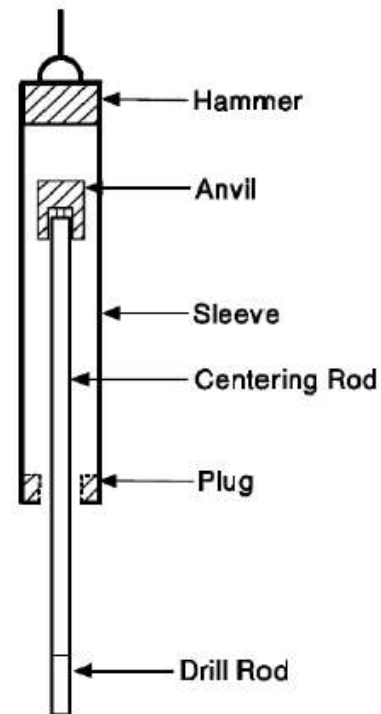
- ▶ Measurements typically every 1,5m
- ▶ Disturbed sample, only for soil classification
- ▶ This method is not Good in cohesive soils
- ▶ Considerable variability

SPT Energy

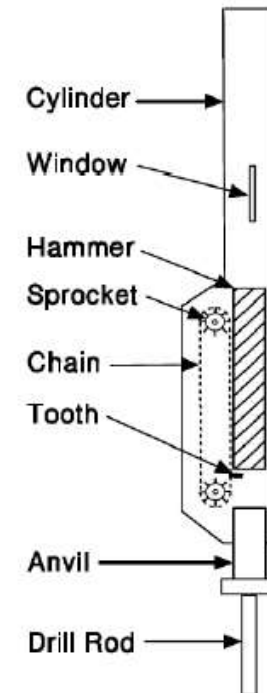
Donut Hammer



Safety Hammer



Automatic Hammer





Safety Hammer

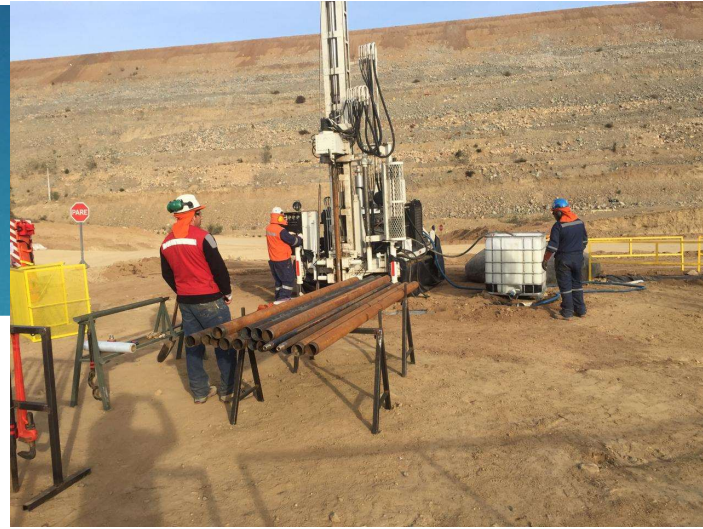
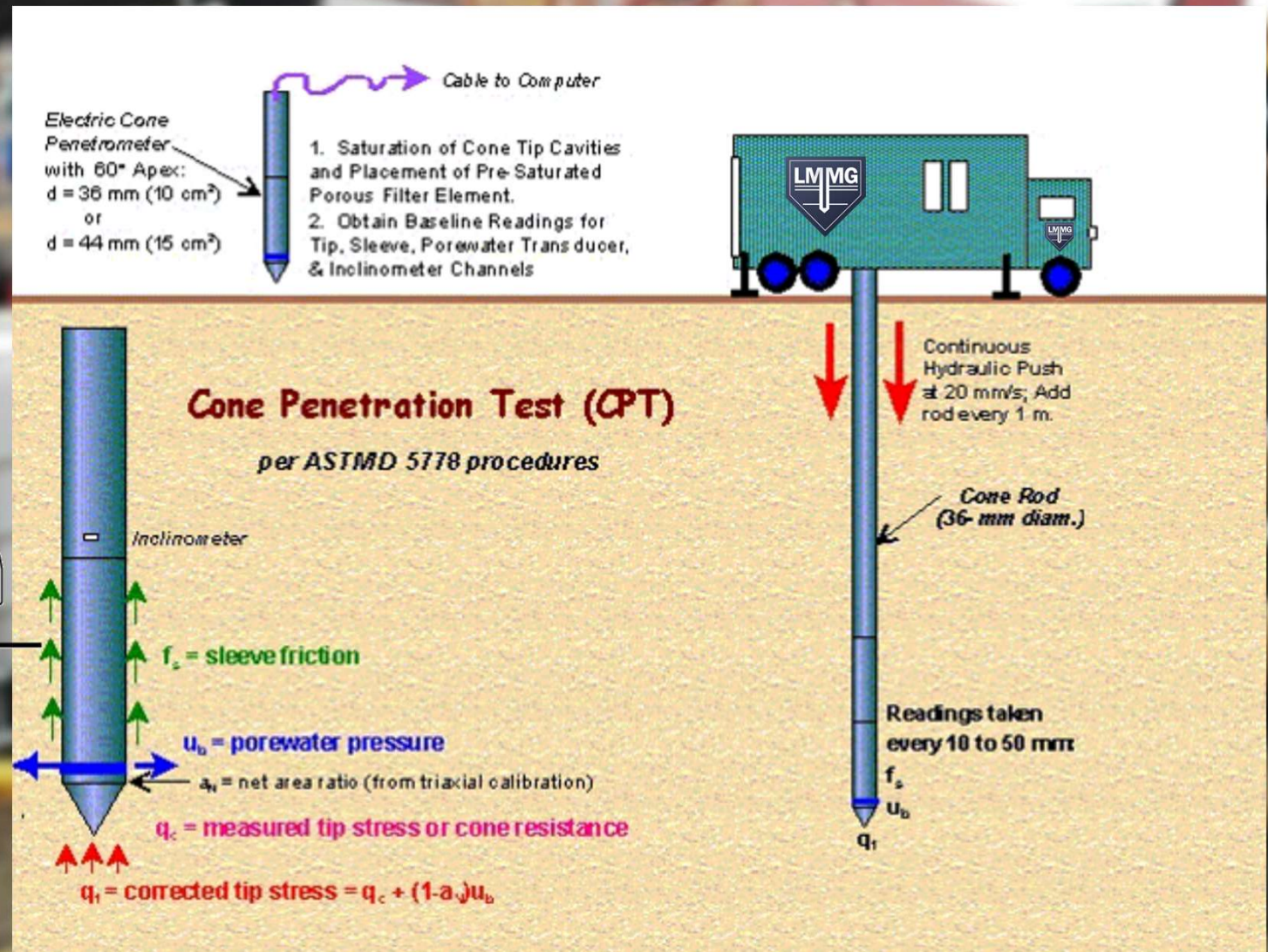
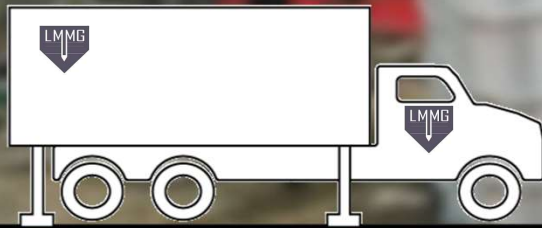


Table 22-2.—Estimated variability of SPT N Values

Cause		Typical raw SPT value in clean sand N = 20	Typical raw SPT value in clay N=10
Basic	Description		
Drilling method	1. Using drilling mud and fluid bypass	20	10
	2. Using drill mud and no fluid bypass	0-20	8-10?
	3. Using clear water with or without bypass	0-20	8-10?
	4. Using hollow-stem augers with or without fluid	0-20	8-10?
	5. 8-inch (20-cm) diameter hole compared to 4 inches (10 cm)	17	8-10?
Sampler	6. Using a larger ID barrel, without the liners	17	9
	7. Using a 3-inch (7.6-cm) OD barrel versus a 2-inch (5-cm) barrel	^e 25-30	10
Procedure	8. Using a blow count rate of 55 blows per minute (bpm) as opposed to 30 bpm	^{e1} 20	^{e1} 10

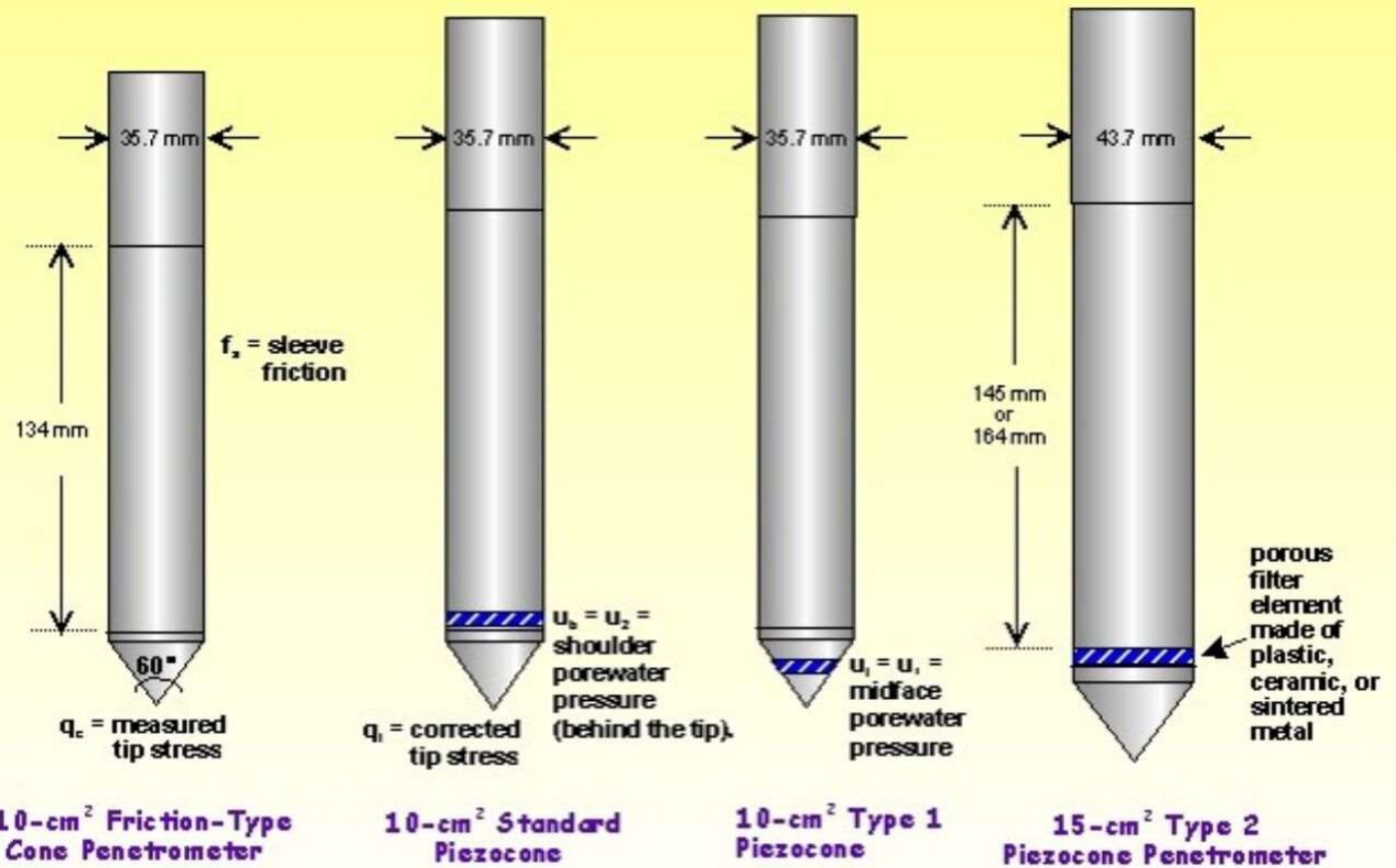
CPT

Cone Penetration Test



CPT

Piezoconos



CPT Trucks



23 Tons Truck.



Portable CPT



Polpaico, Til Til

CPT Ventajas

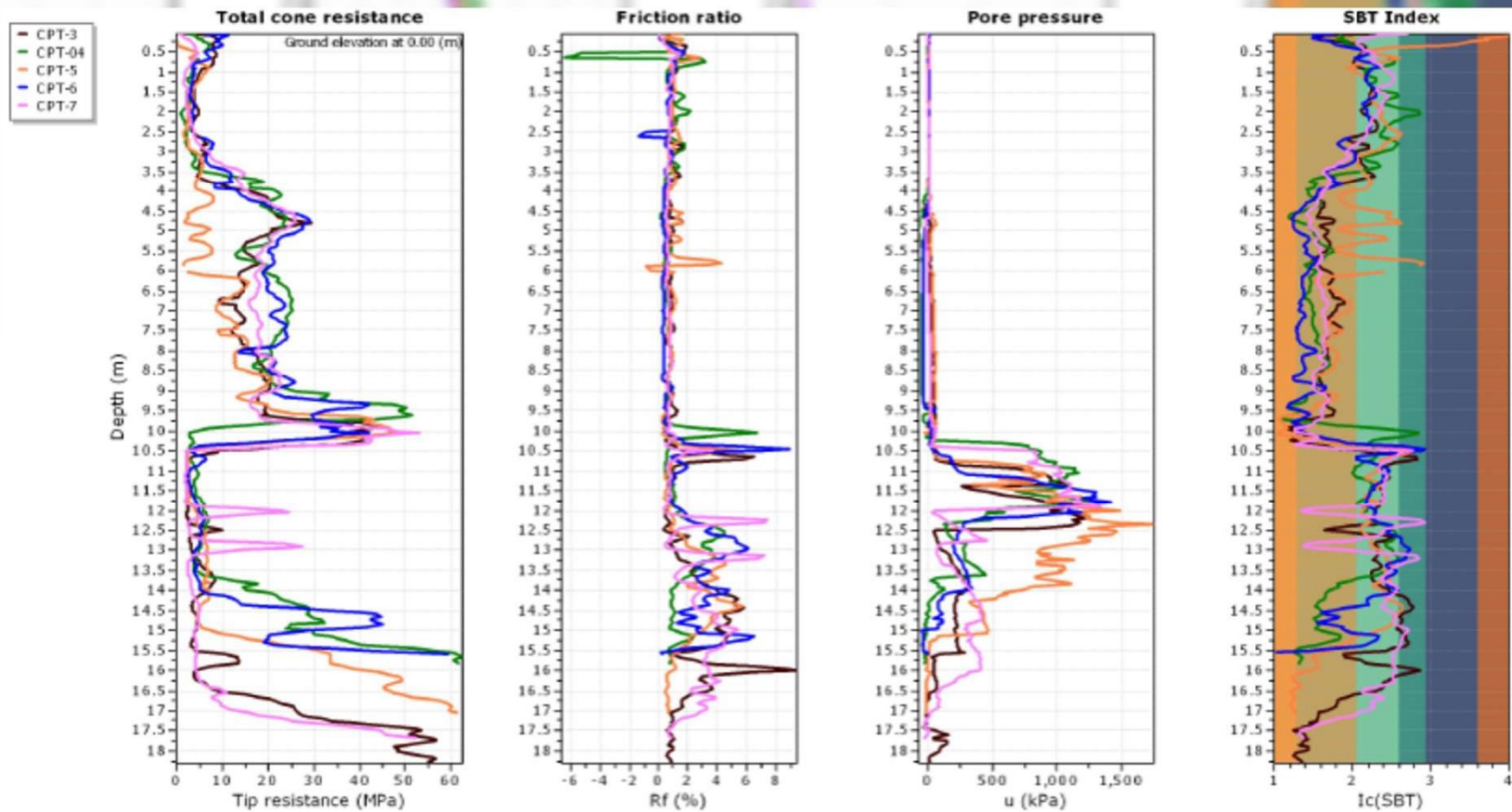
- Soil profile based on behavior. 100 m per day.
- Almost continuous data from the soil profile
- Real-time data.
- It can be complemented easily with downhole tests, dissipation tests and soil sampling.

LMMG



CPT

In-situ tests



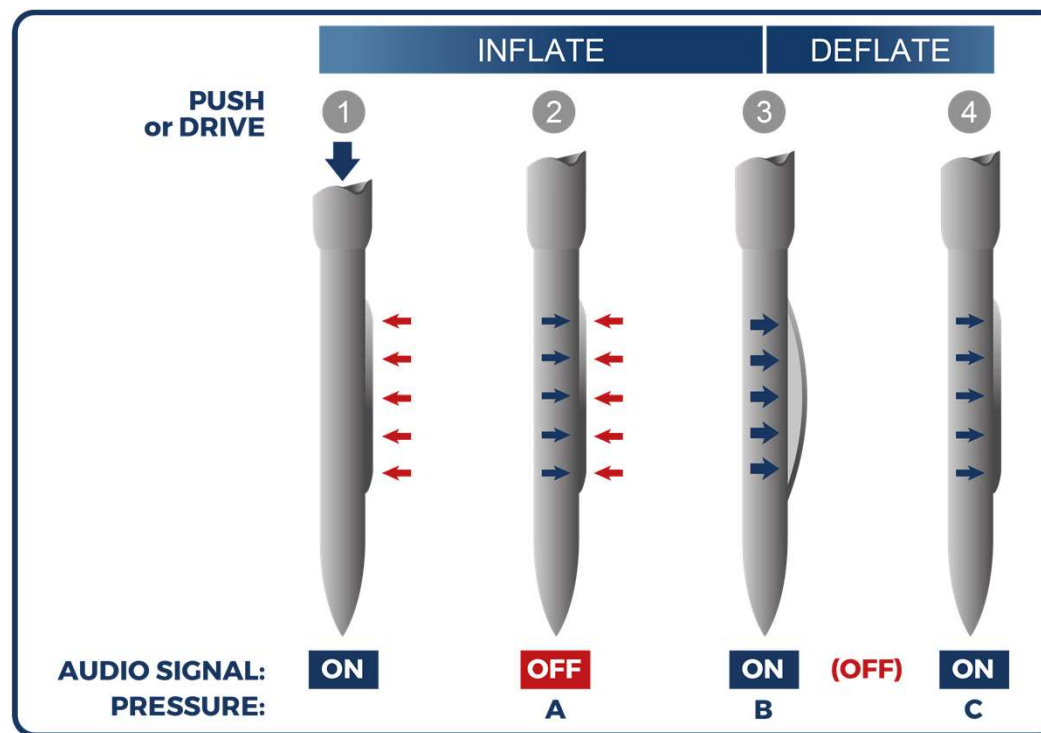
DMT MARCHETTI DILATOMETER



Main DMT components



DMT Test Sequence: A, B, C readings



Vane Shear Test

CPT TRUCKS





Inch-Pound Units:

$$K = (\pi/1728) \times (D^2H/2) \times [1 + (D/3H)]$$

Metric Units:

$$K = (\pi/10^6) \times (D^2H/2) \times [1 + D/3H]$$

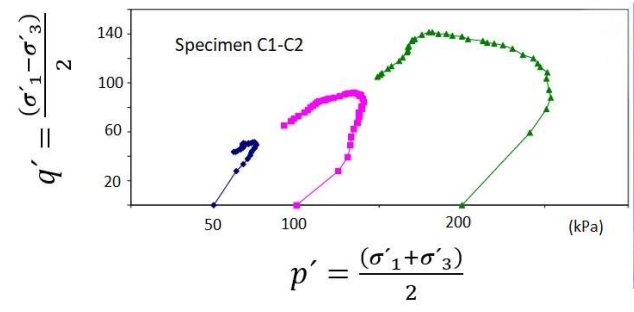
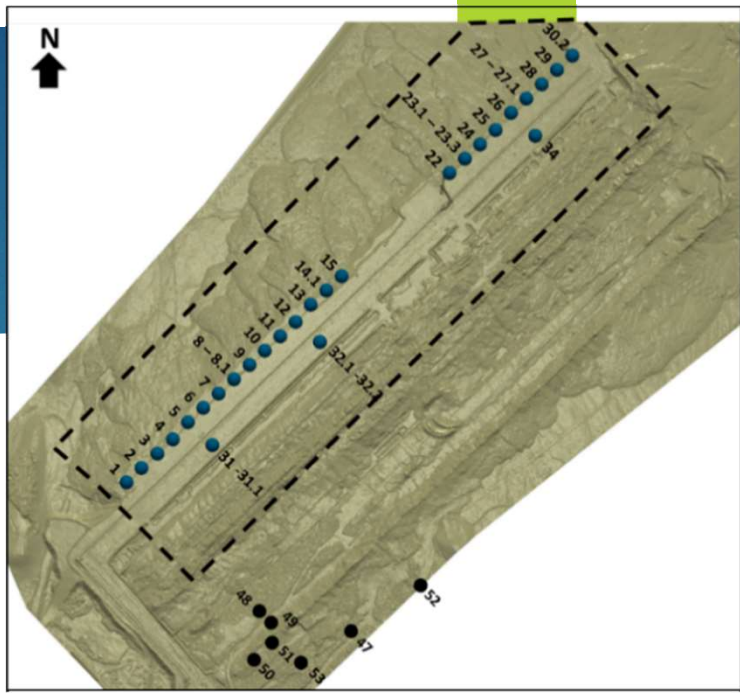
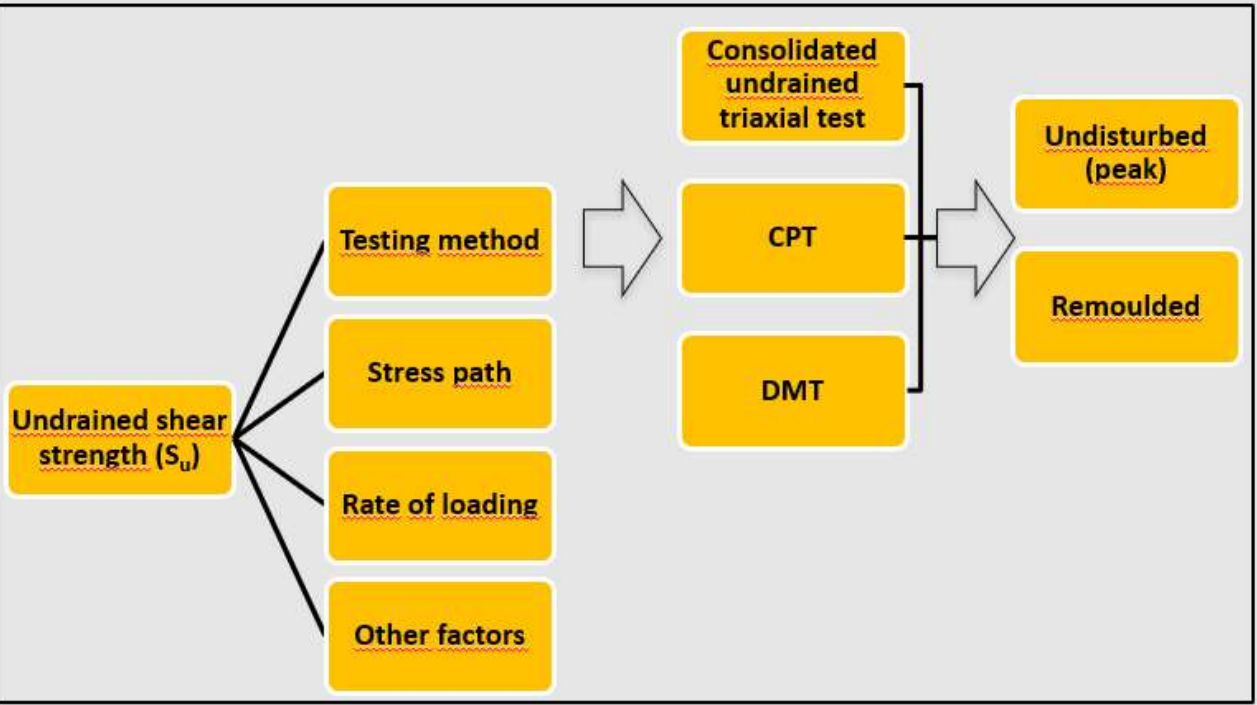
ASTM D 2573

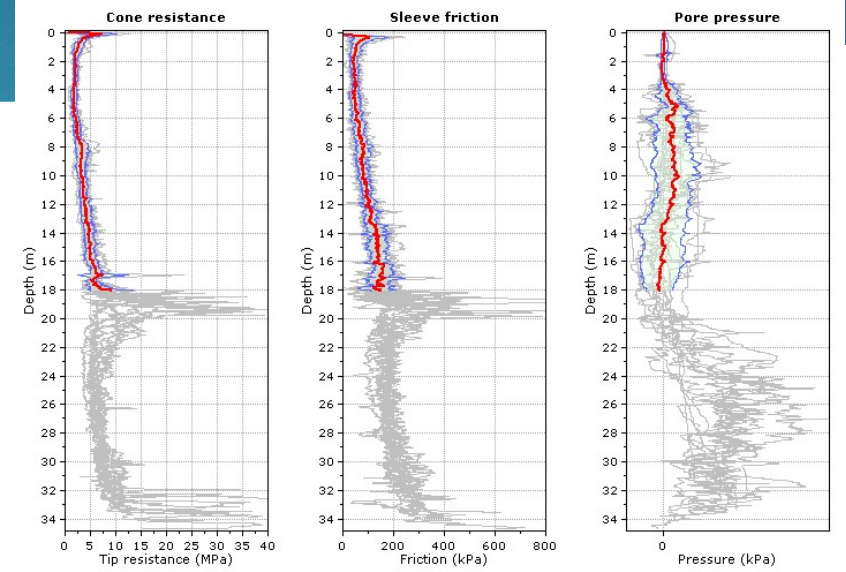
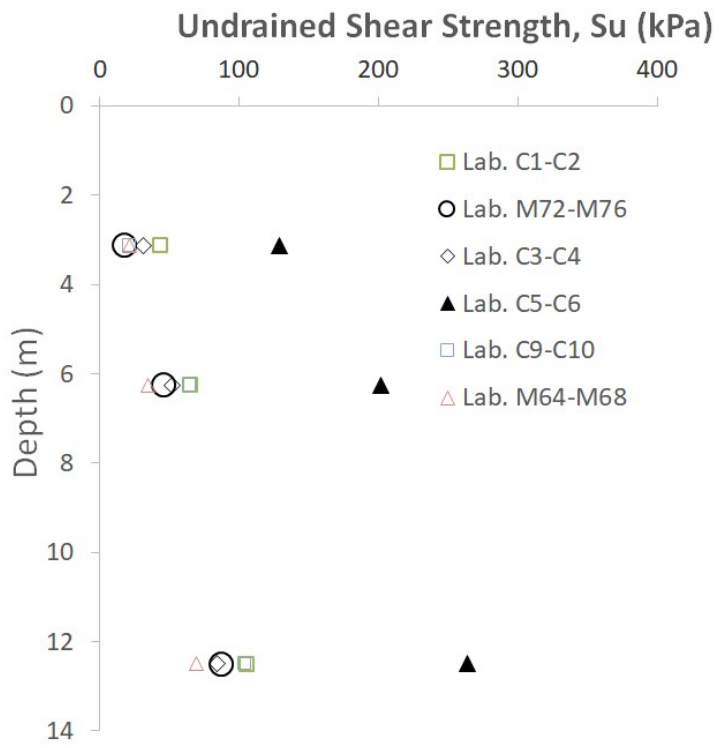
A few examples

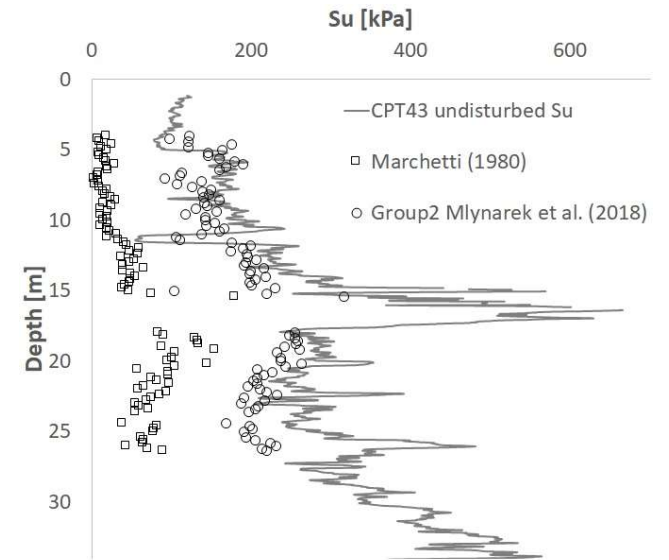
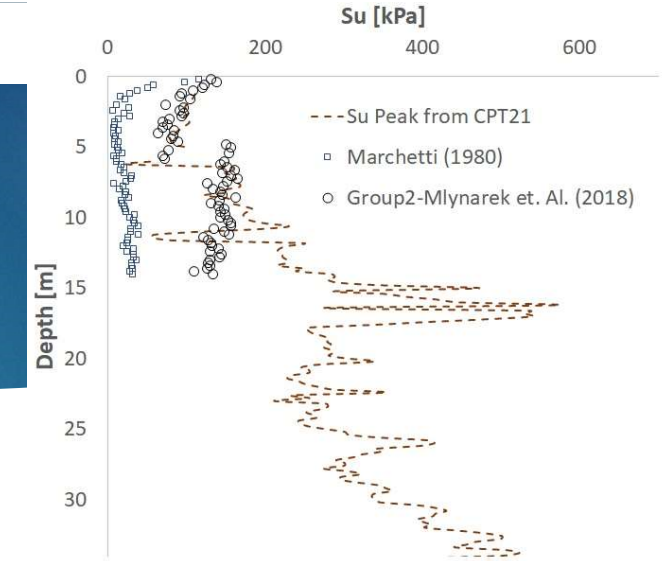
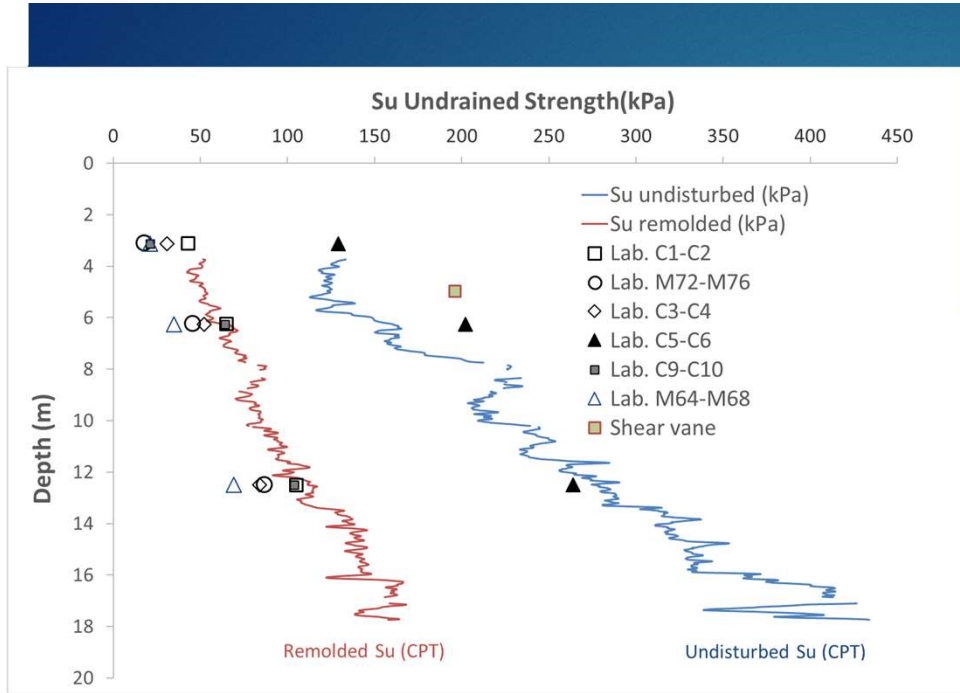


Undrained
strength

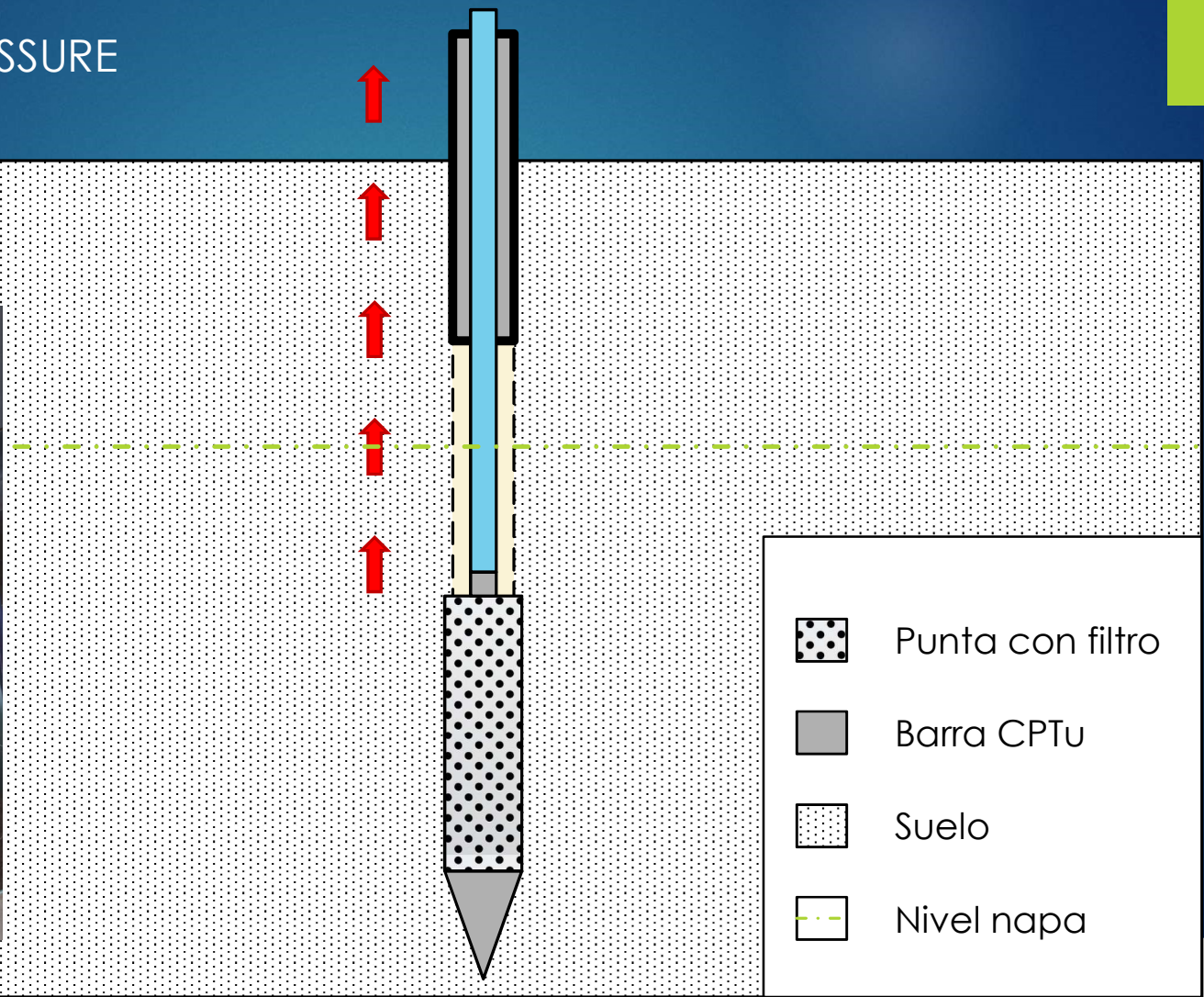








PORE WATER PRESSURE DISTRIBUTION

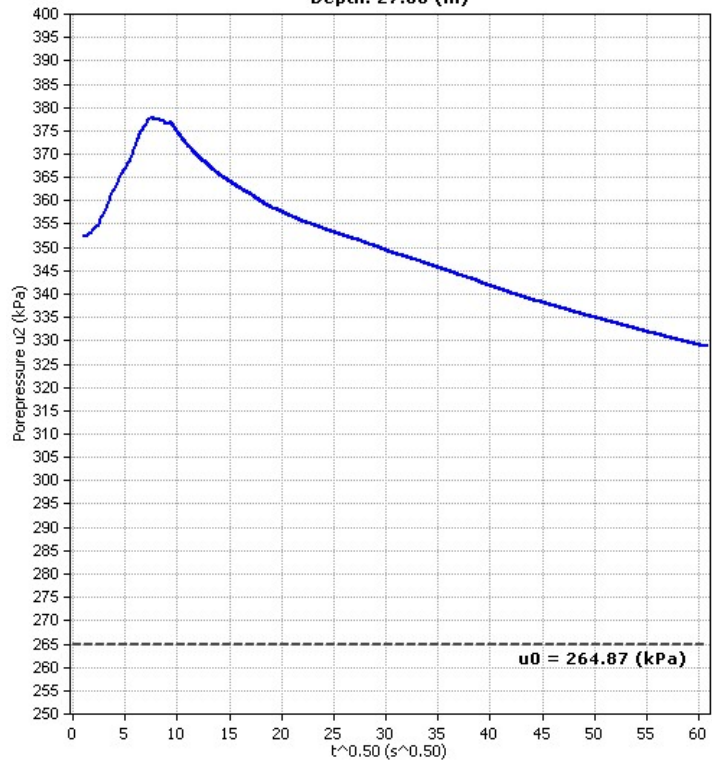


Piezómetro	Última conexión exitosa	Ubicación	Profundidad
PZ1	9-11-2022	CPT01	26
PZ2	9-11-2022	CPT03	25
PZ3	9-11-2022	CPT19	19,2
PZ4	9-11-2022	CPT21	19,5
PZ5	9-11-2022	CPT35	8,5
PZ6	9-11-2022	CPT43	17
PZ7	9-11-2022	CPT43	24
PZ8	9-11-2022	CPT46	20
PZ9	9-11-2022	CPT51	18,5
PZ10	9-11-2022	CPT48	22

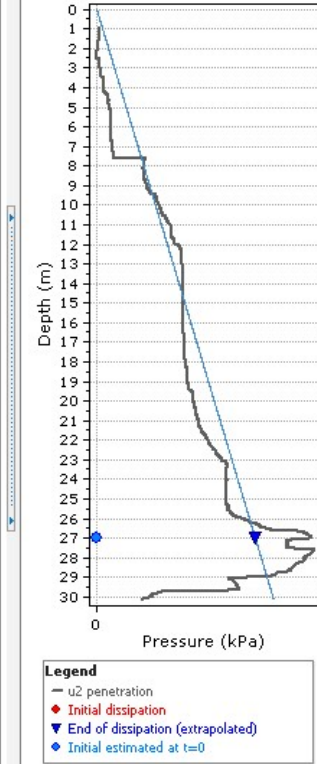
PIEZÓMETROS



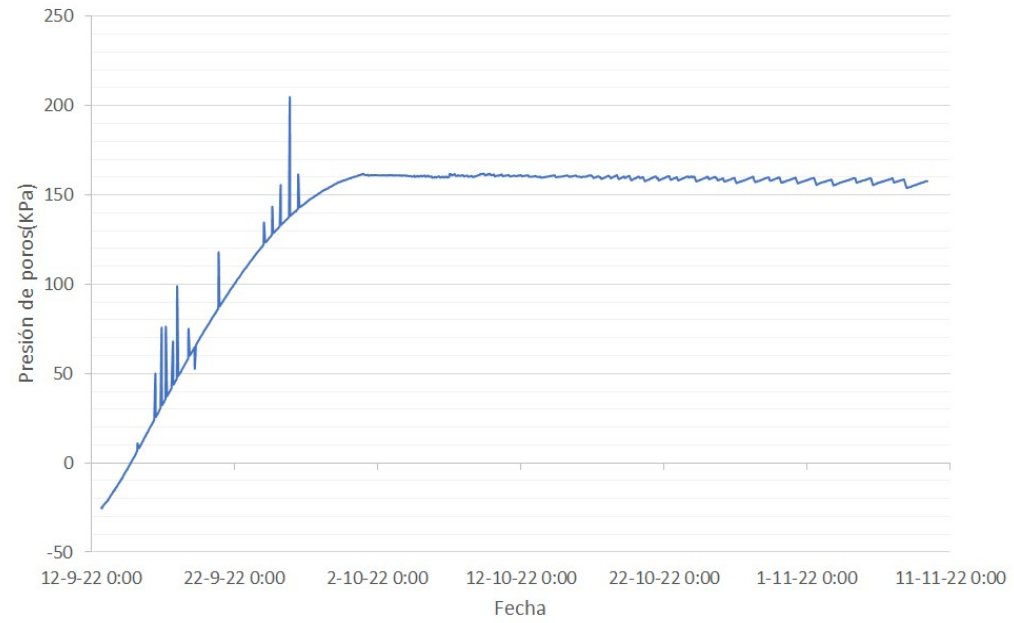
Piezocone Dissipation Test: CPT 34
Depth: 27.00 (m)

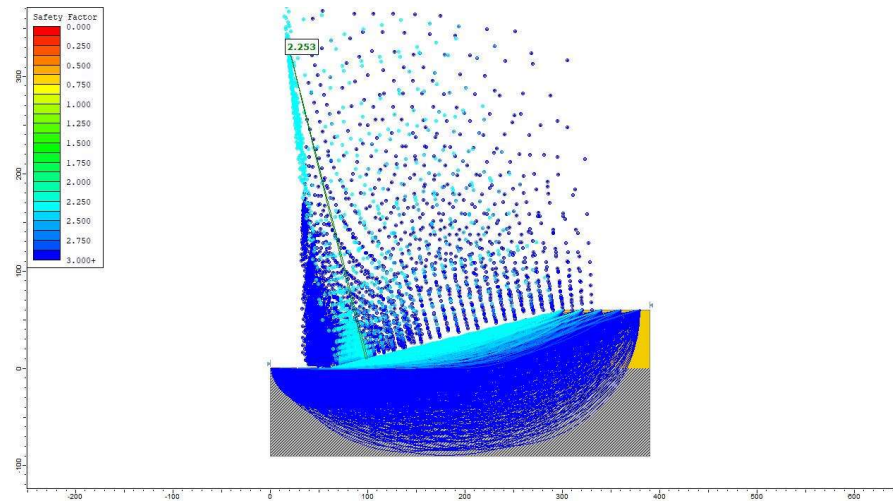
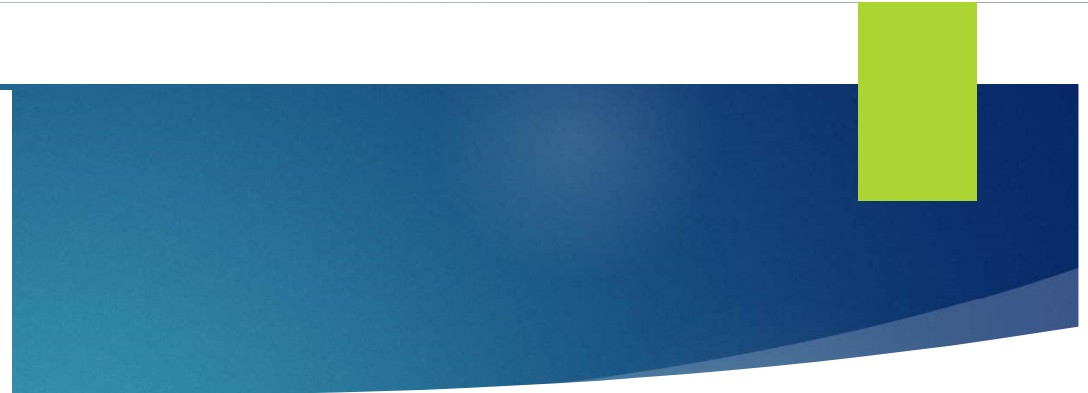
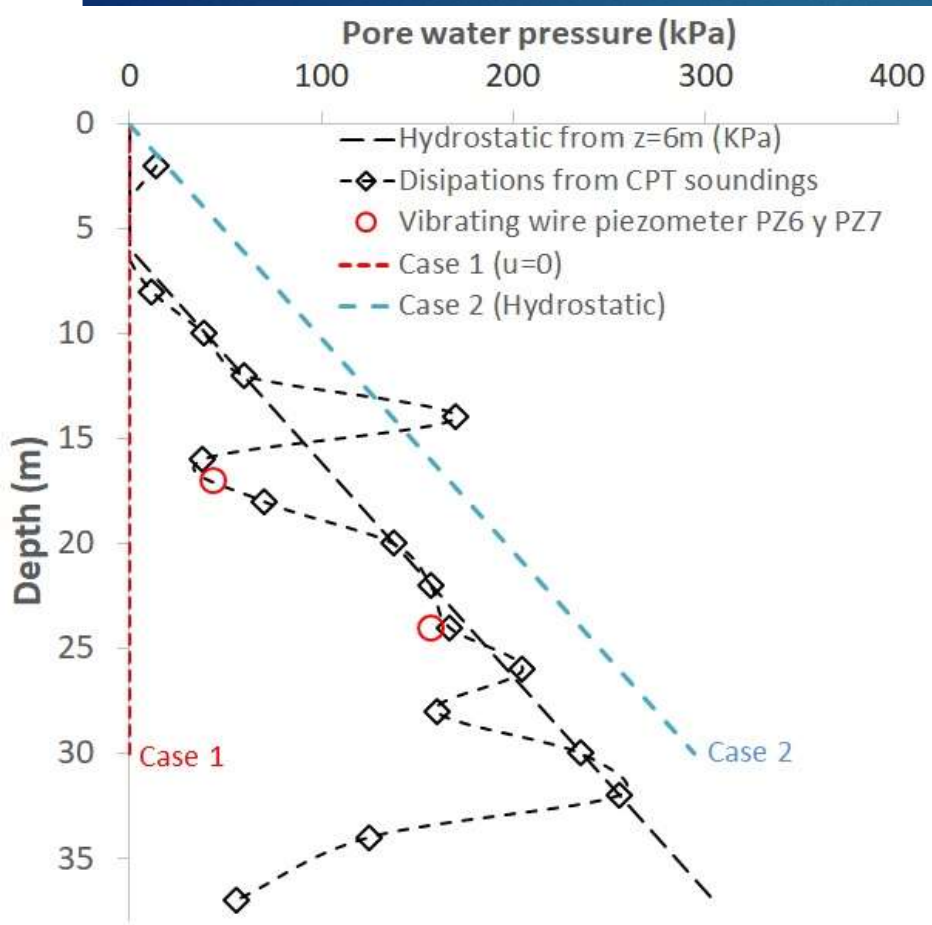


Pore pressure



Sensor PZ7(Kpa)





ATACAMA DESERT



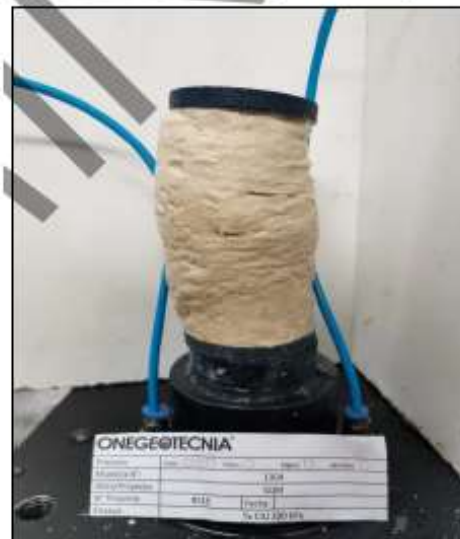


CIU TRIAXIAL TESTS





Probeta 200 kPa antes de ensayo



Probeta 200 kPa después de ensayo



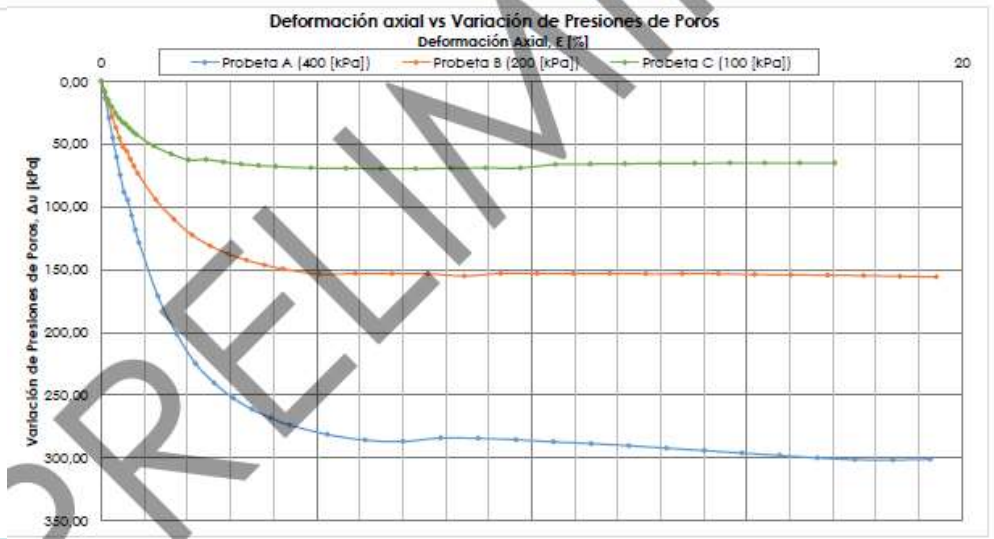
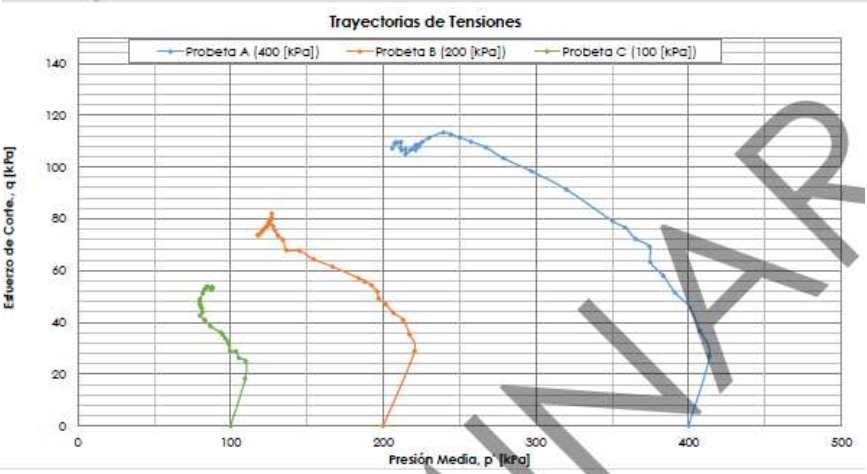
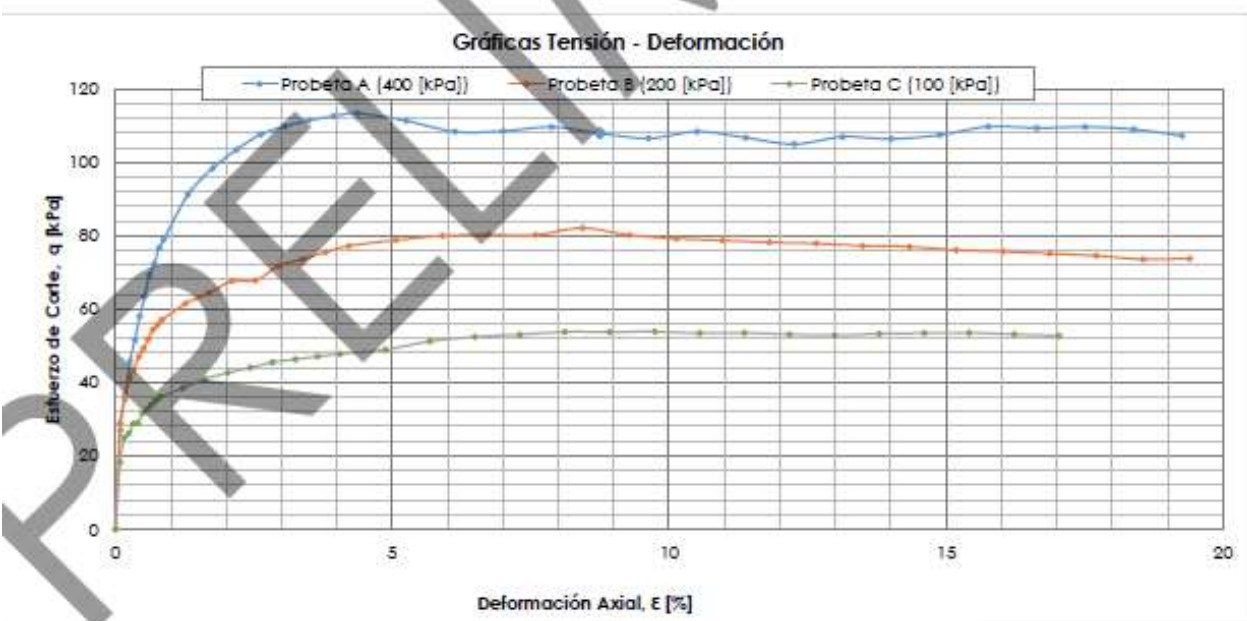
Probeta 400 kPa antes de ensayo



Probeta 400 kPa después de ensayo



► Sample M2





Probeta 200 kPa antes de ensayo



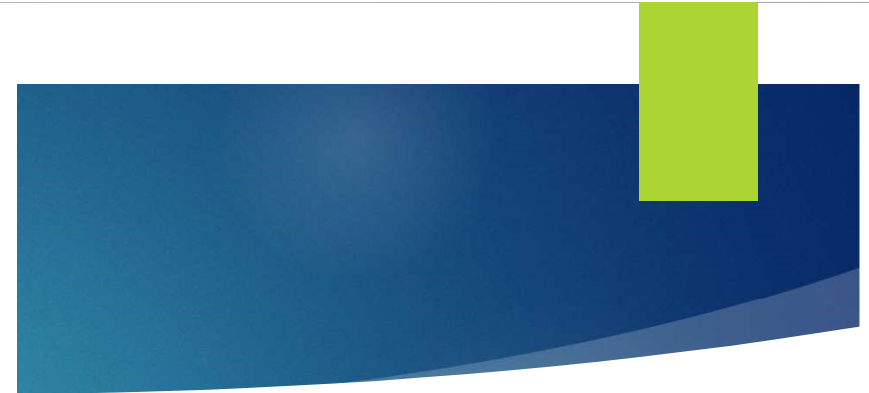
Probeta 200 kPa después de ensayo



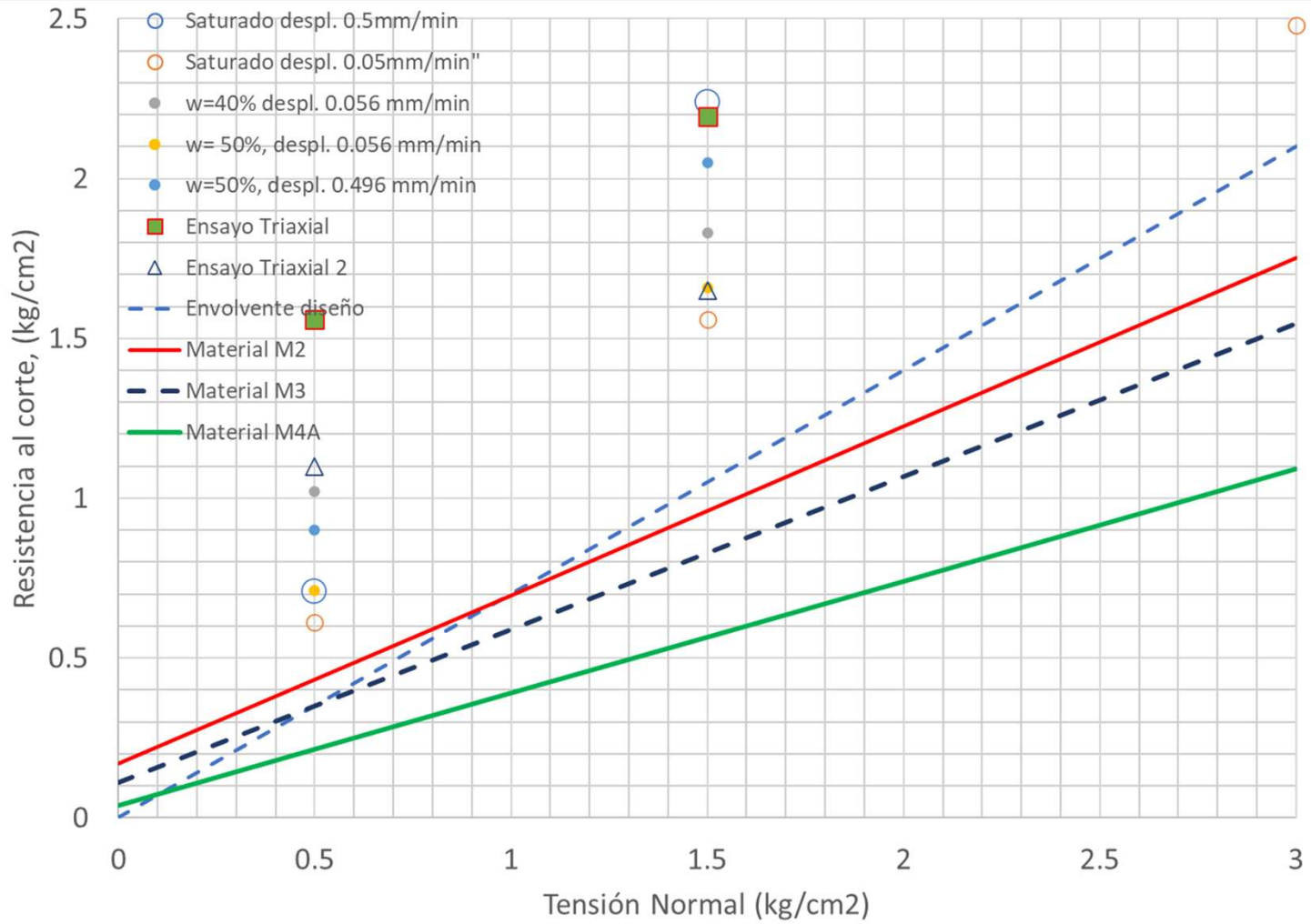
Probeta 400 kPa antes de ensayo



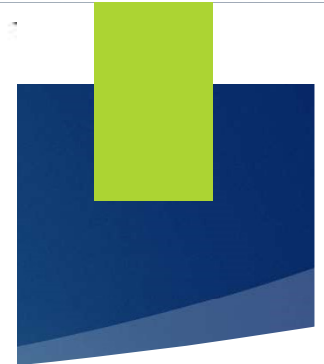
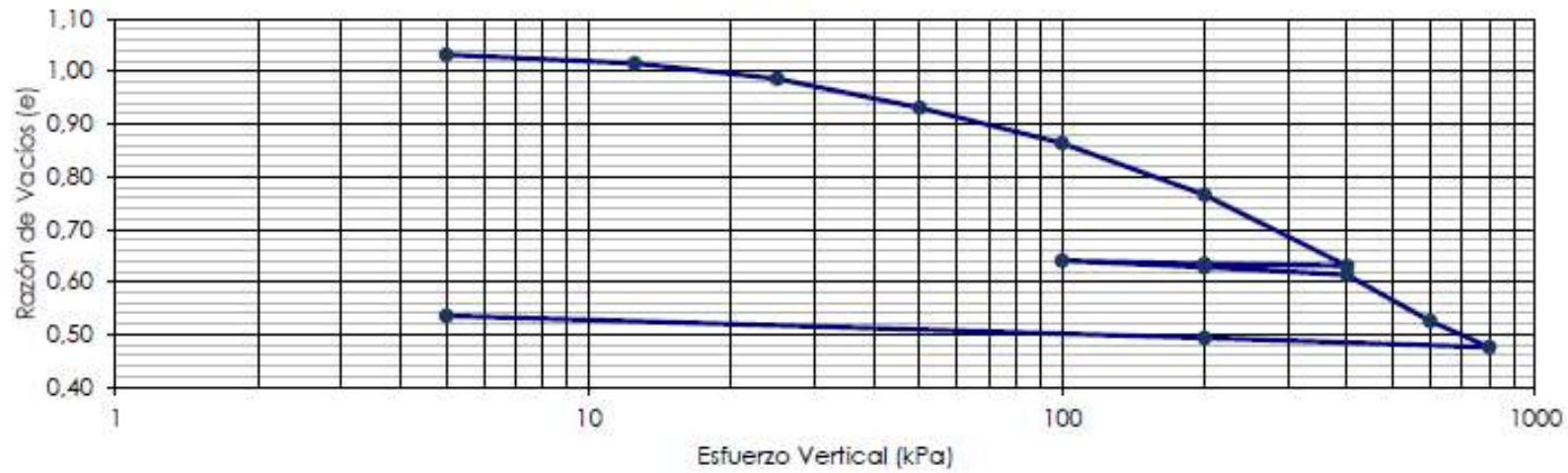
Probeta 400 kPa después de ensayo



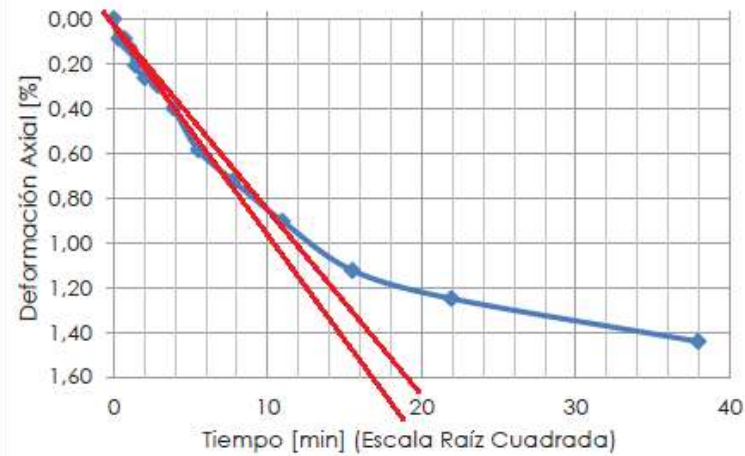
Sample M3



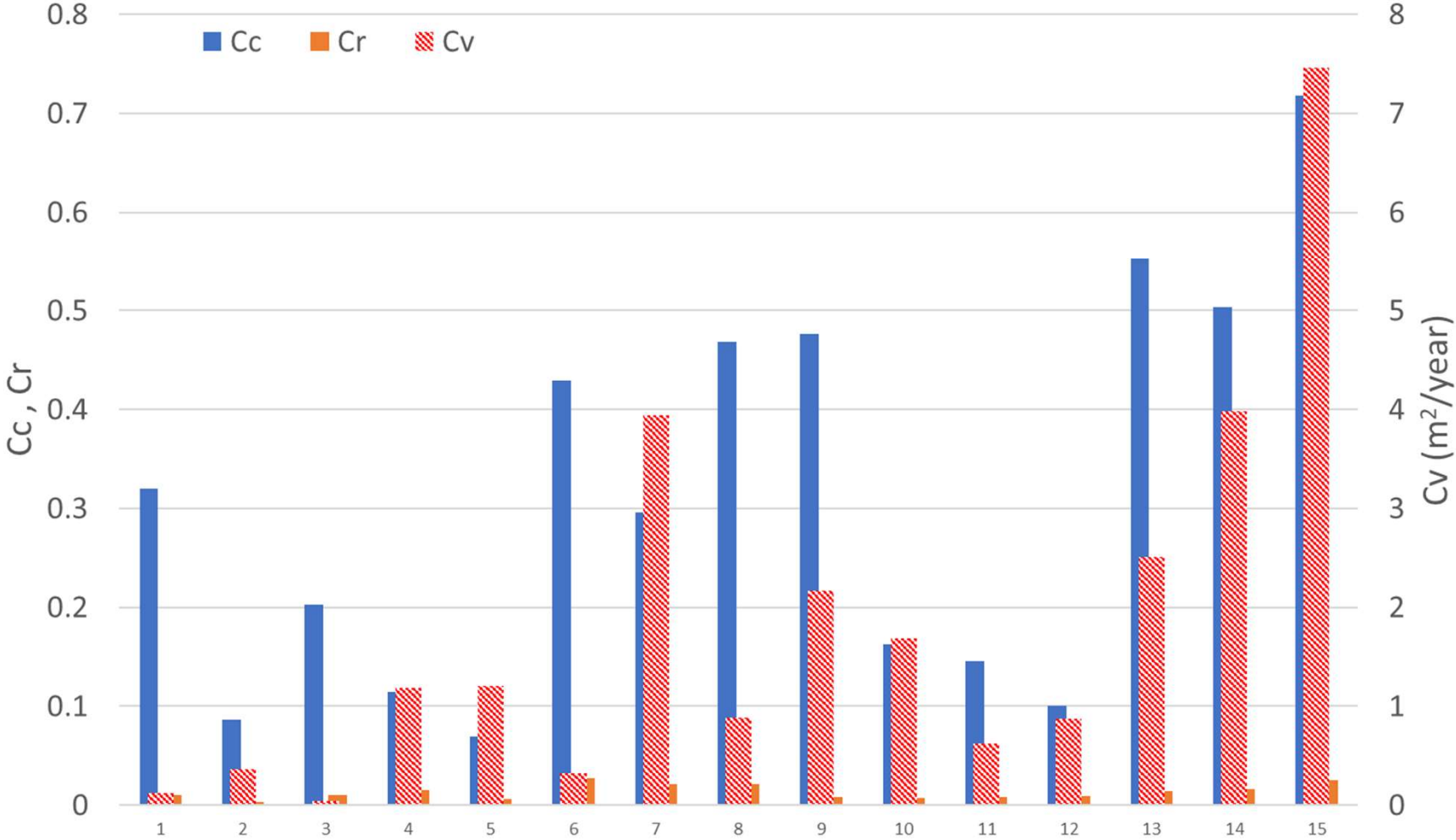
Ensayo de Consolidación



Curva Tiempo - Deformación para 200 [kPa]



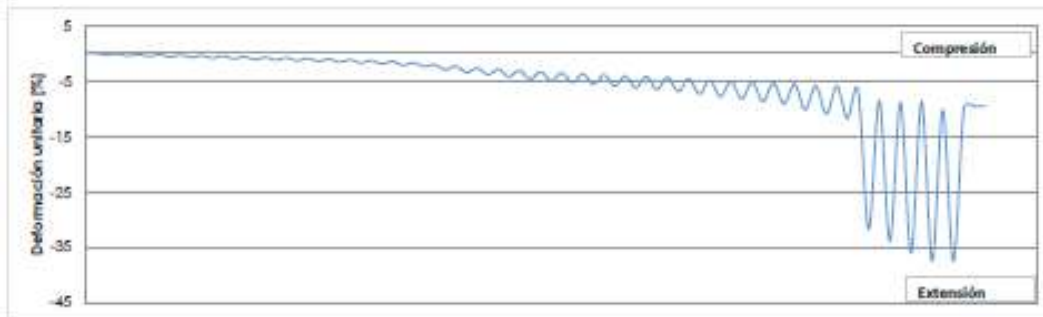
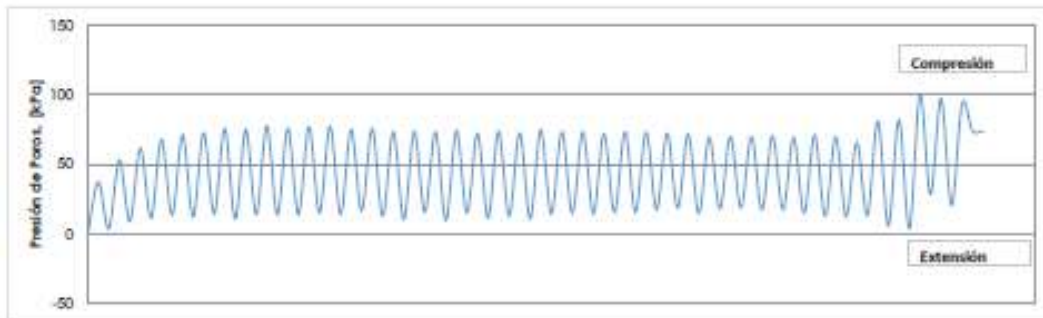
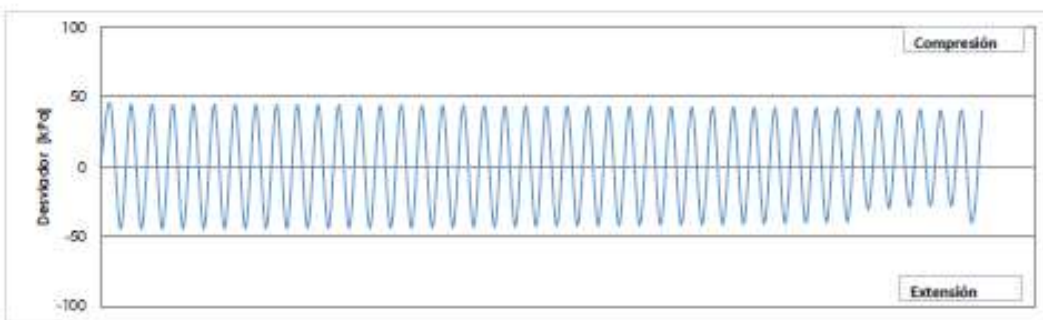
Consolidación Sales

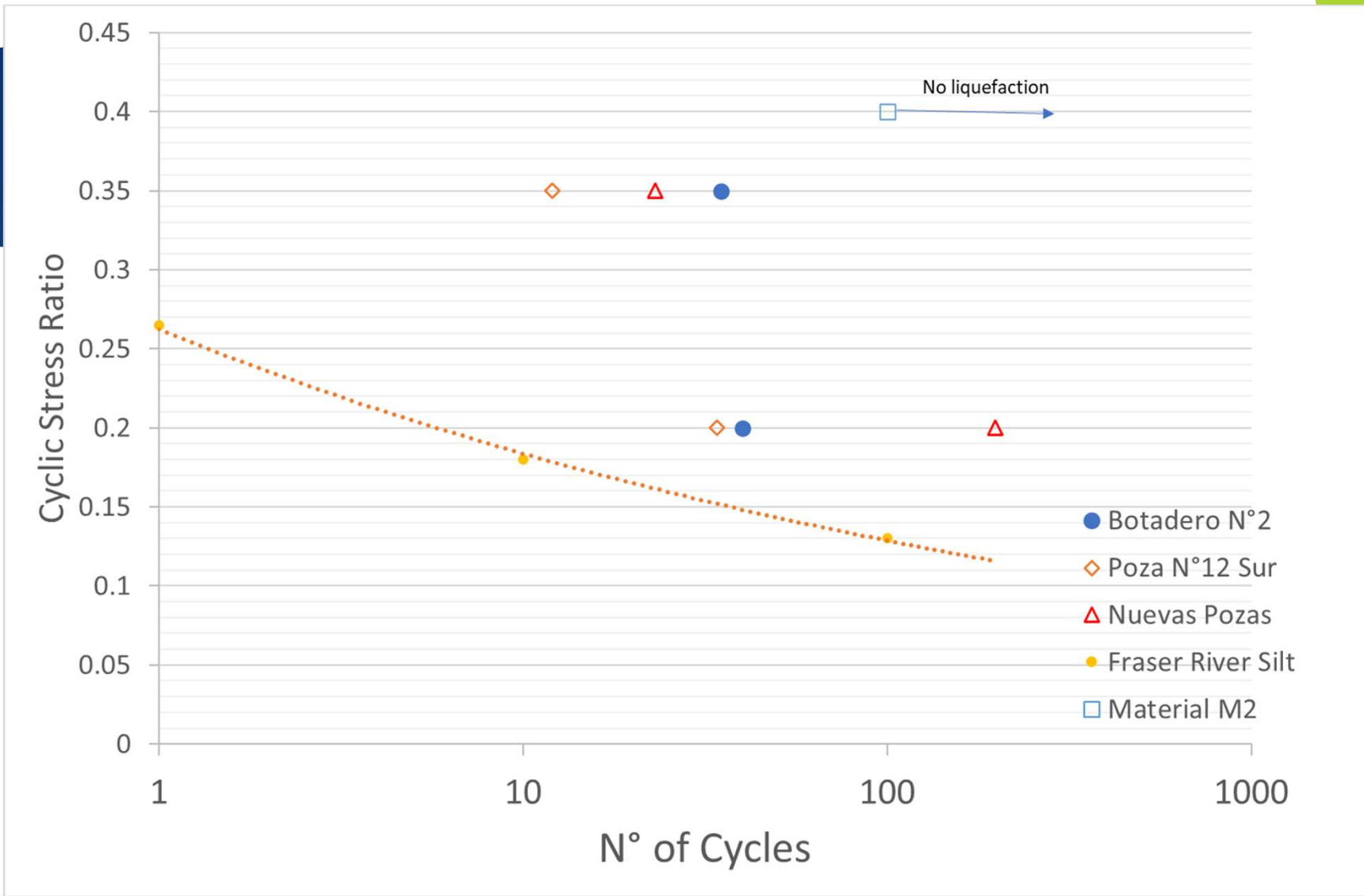


Cyclic Triaxial Tests



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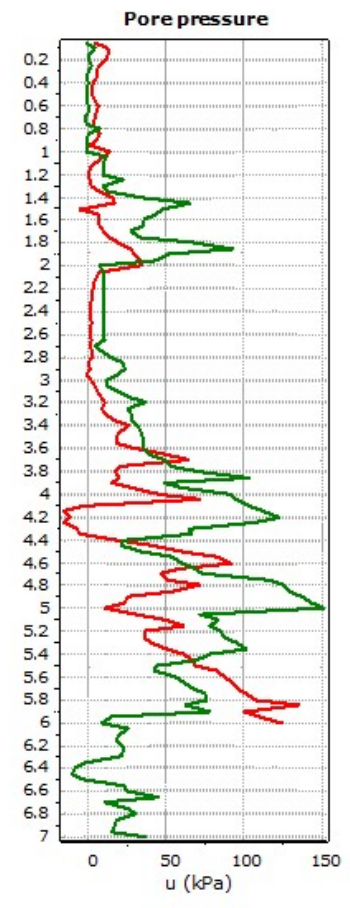
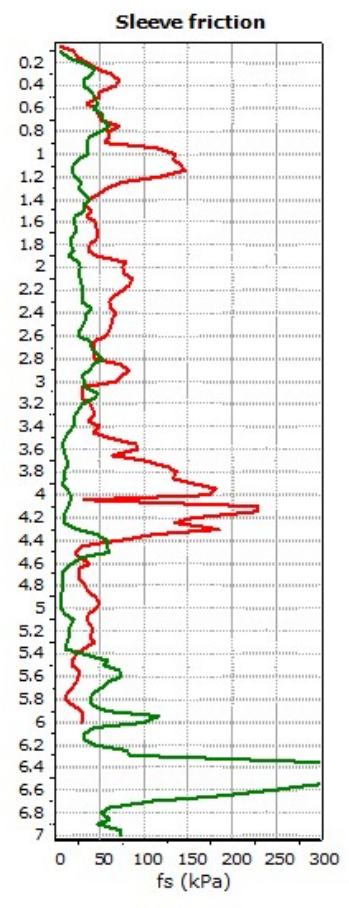
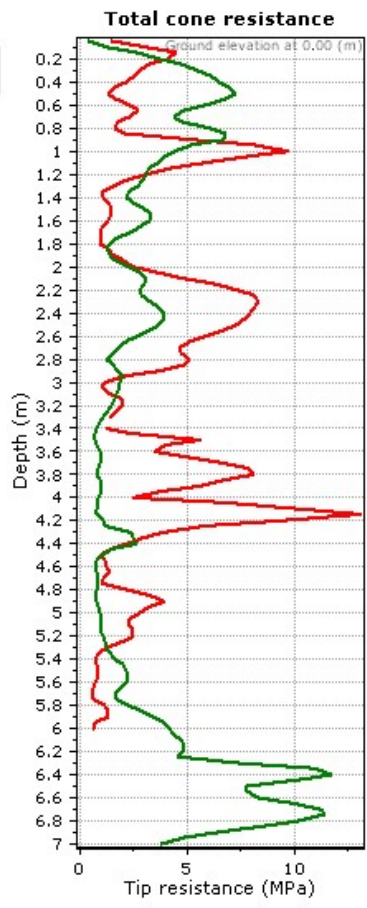




Sondajes CPTu, CPT1-F3



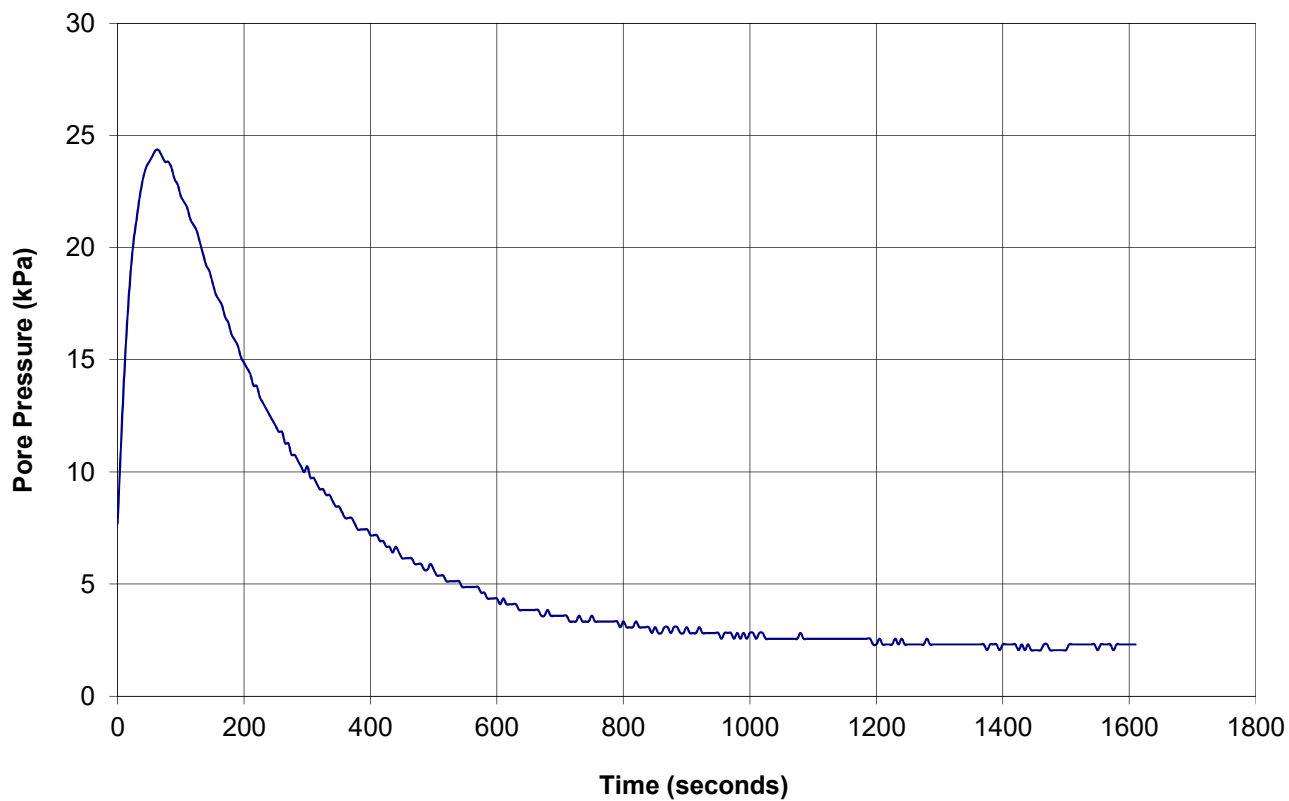
— CPTu01-F-III
— CPTu02-F-III



CPT5-F3



Disipation tests



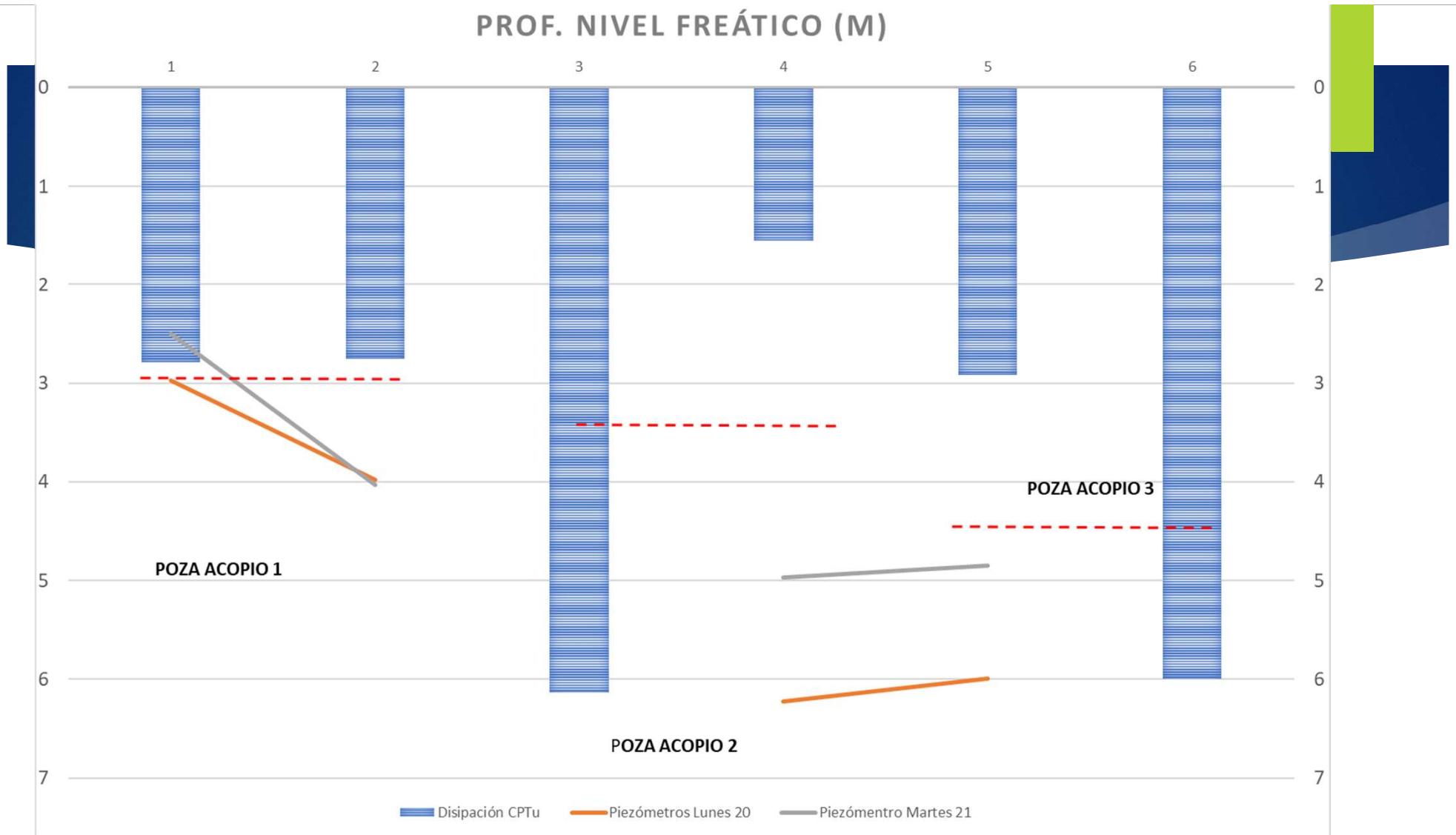
▶ Sondaje CPT1-F3

▶ Ubicación nivel freático

▶ Prof. 2.79m

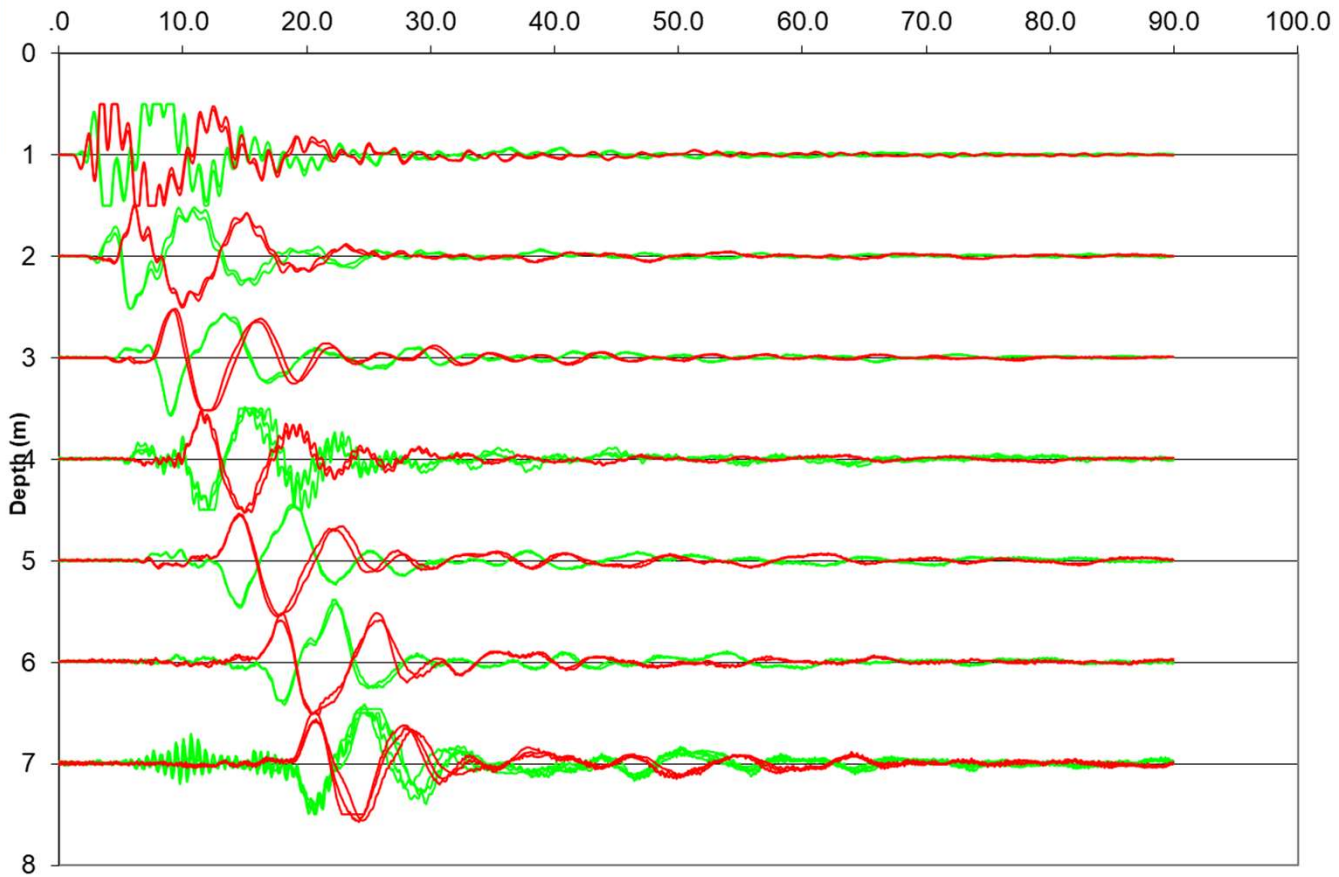


PROF. NIVEL FREÁTICO (M)

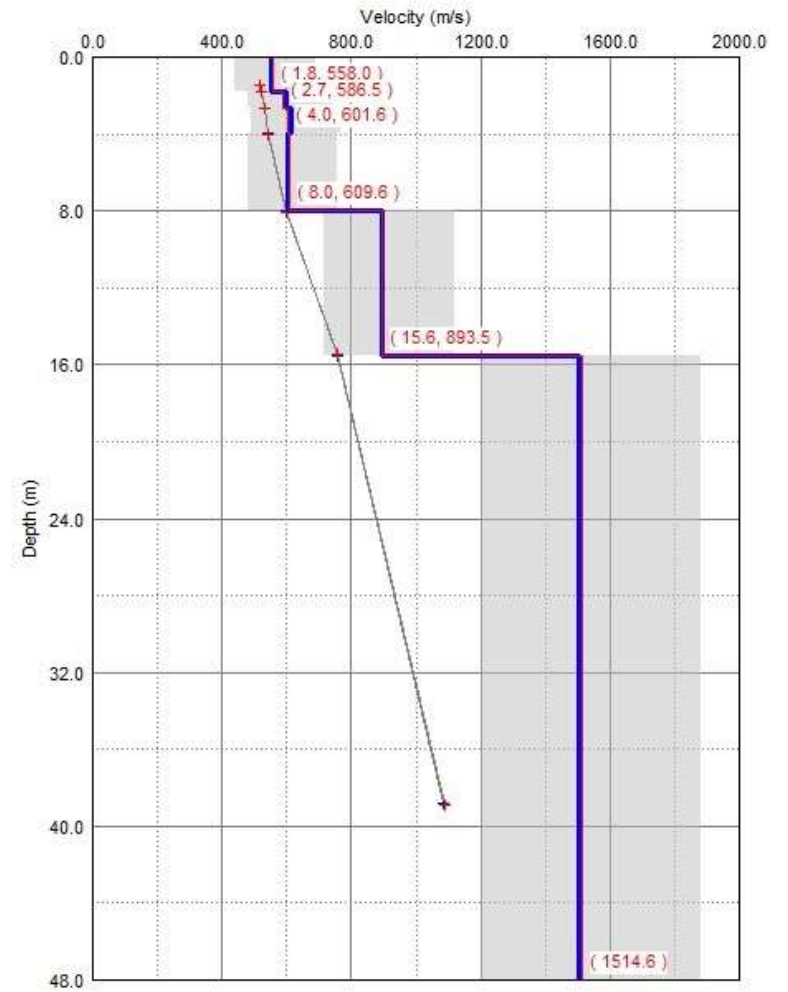


Waveforms for Sounding CPTu03

Time (ms)

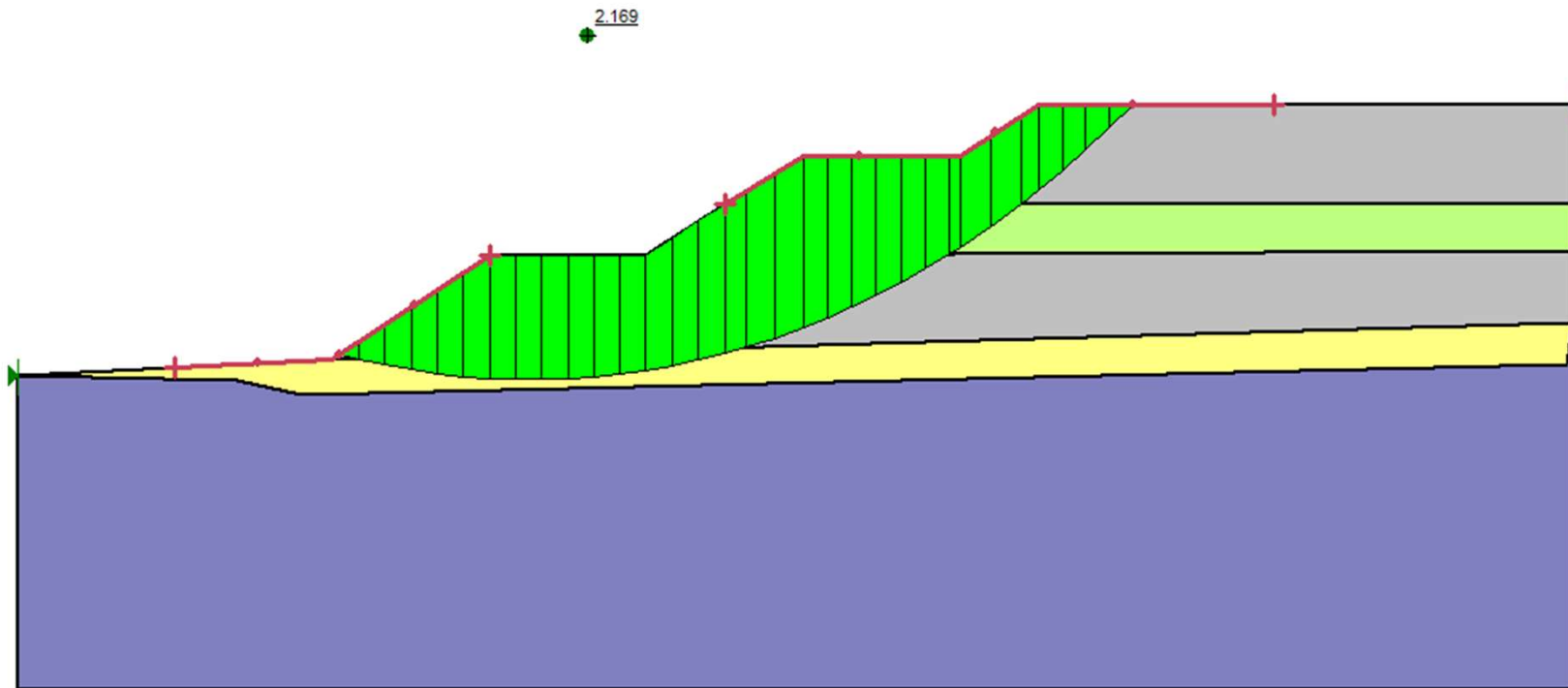


Terreno de fundación



Análisis con altura de 12.5m máximo

Análisis estático, M1 en estado suelto, M0 40 KPa no consolidado



M0=40KP
α
M1
denso
Kh =0.28

