WORKSHOP ON PENETRATION TESTING AND OTHER GEOMECHANICAL ISSUES

Pisa 14 June 2016 – ROOM F8

CPTU IN UNUSUAL SOILS

Diego Lo Presti, Barbara Cosanti, Ilaria Giusti, Nicola Perilli

(d.lopresti@ing.unipi.it)

UNIVERSITA' DI PISA

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

LECTURE OUTLINE

- DEFINITION OF UNUSUAL SOILS
- CHARACTERIZATION (IDENTIFICATION) OF PARTIALLY SATURATED FINE- GRAINED SOILS
- UNDERCONSOLIDATED SILTY SOILS

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

UNUSUAL SOILS

- LAYERED;
- PARTIALLY SATURATED;
- UNDERCONSOLIDATED;
- INTERMEDIATE PERMEABILITY;
- COMPACTED SOILS

EQUIPMENT AT UNIPI

CPTU EQUIPMENTS

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

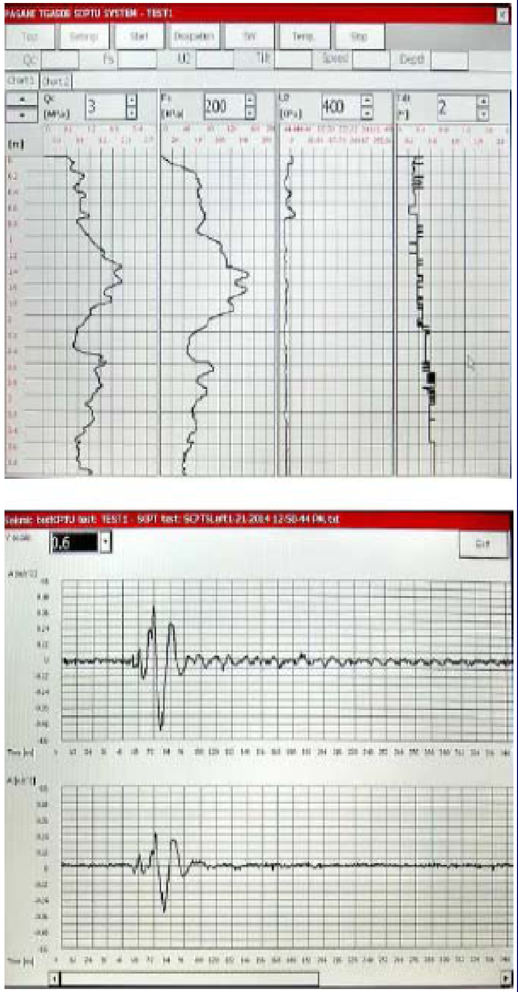
Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

SCPTU EQUIPMENT

- 2 TX accelerometers at 0.5 m distance
- Connector
- Source



Screenshot of CPTu and SCPTu test

SCPTU - ROTOSEIS

Equipment: Seismic piezocone (source 2: Rotoseis) Mayne 2010

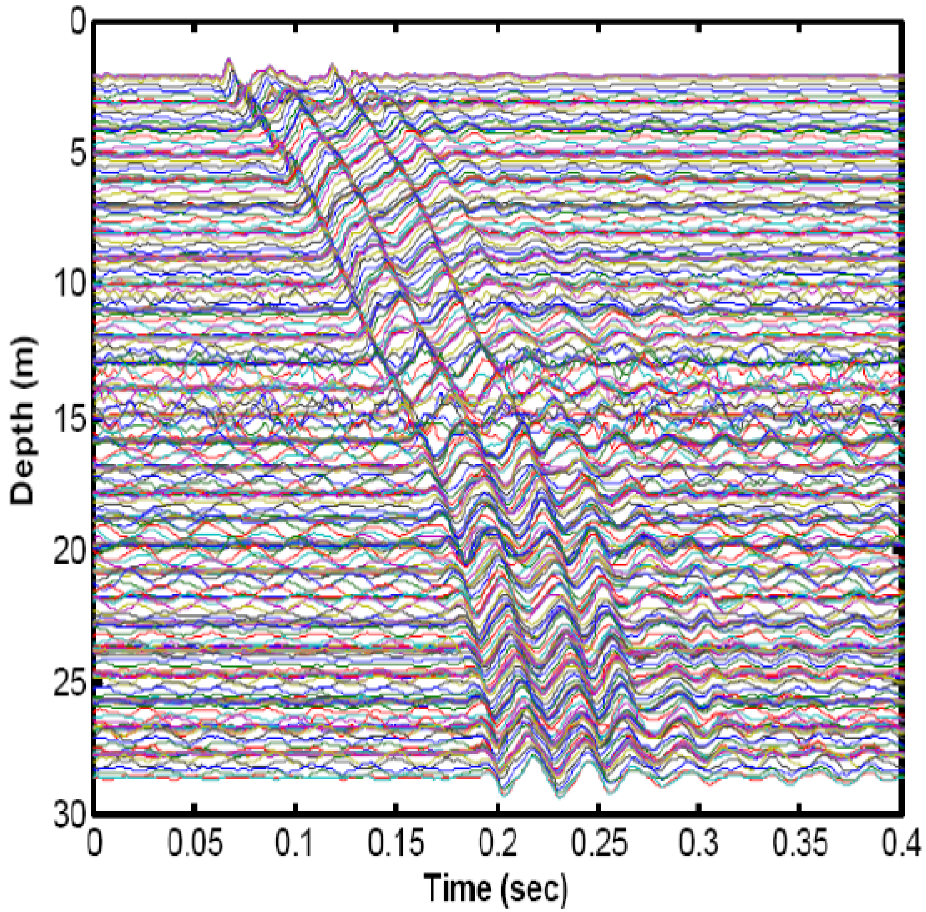
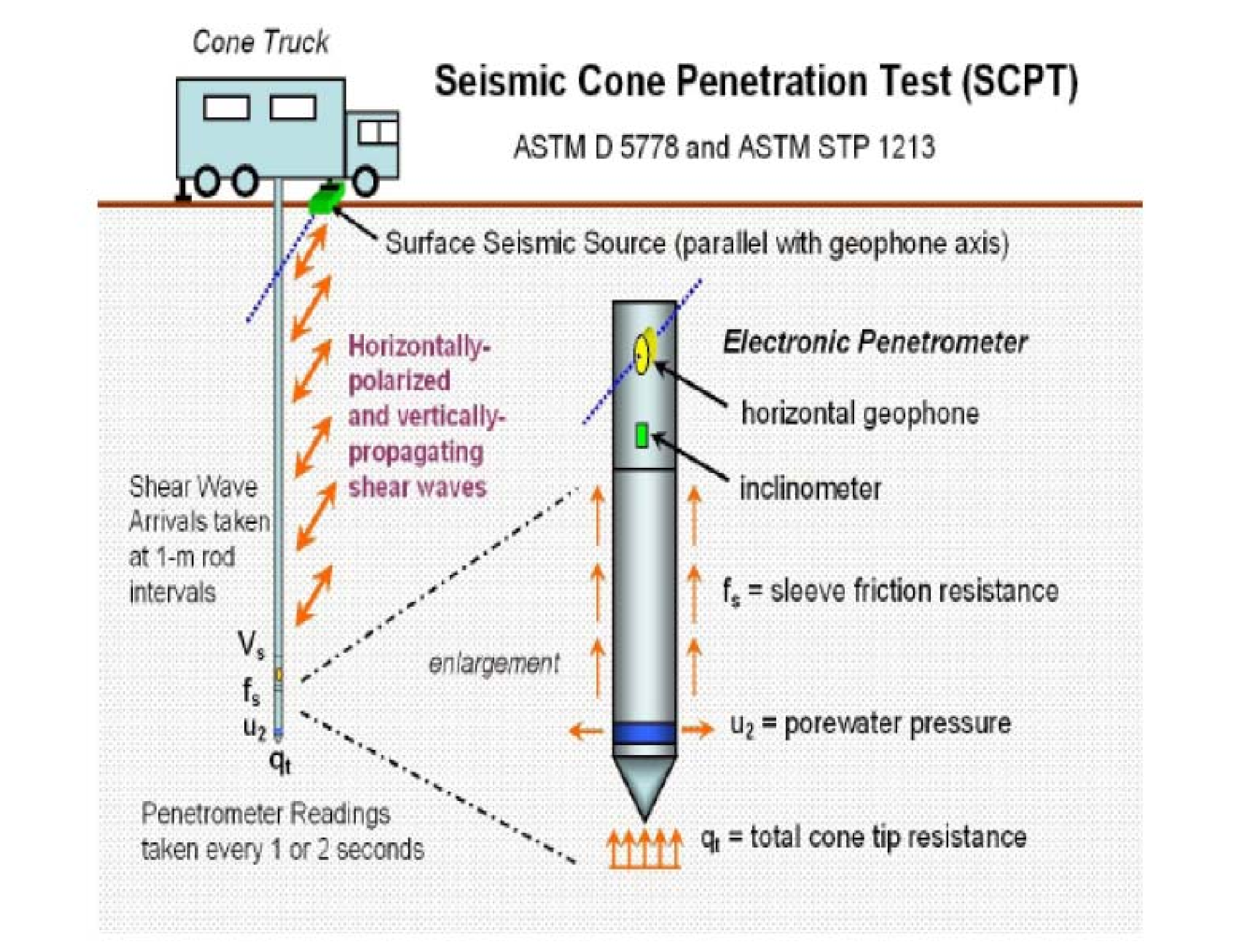


Figure 25. Summary paste-up of wavelets from continuous seismic cone testing in Charleston, SC (McGillivray & Mayne, 2008).

SCPTU INTERPRETATATION



L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

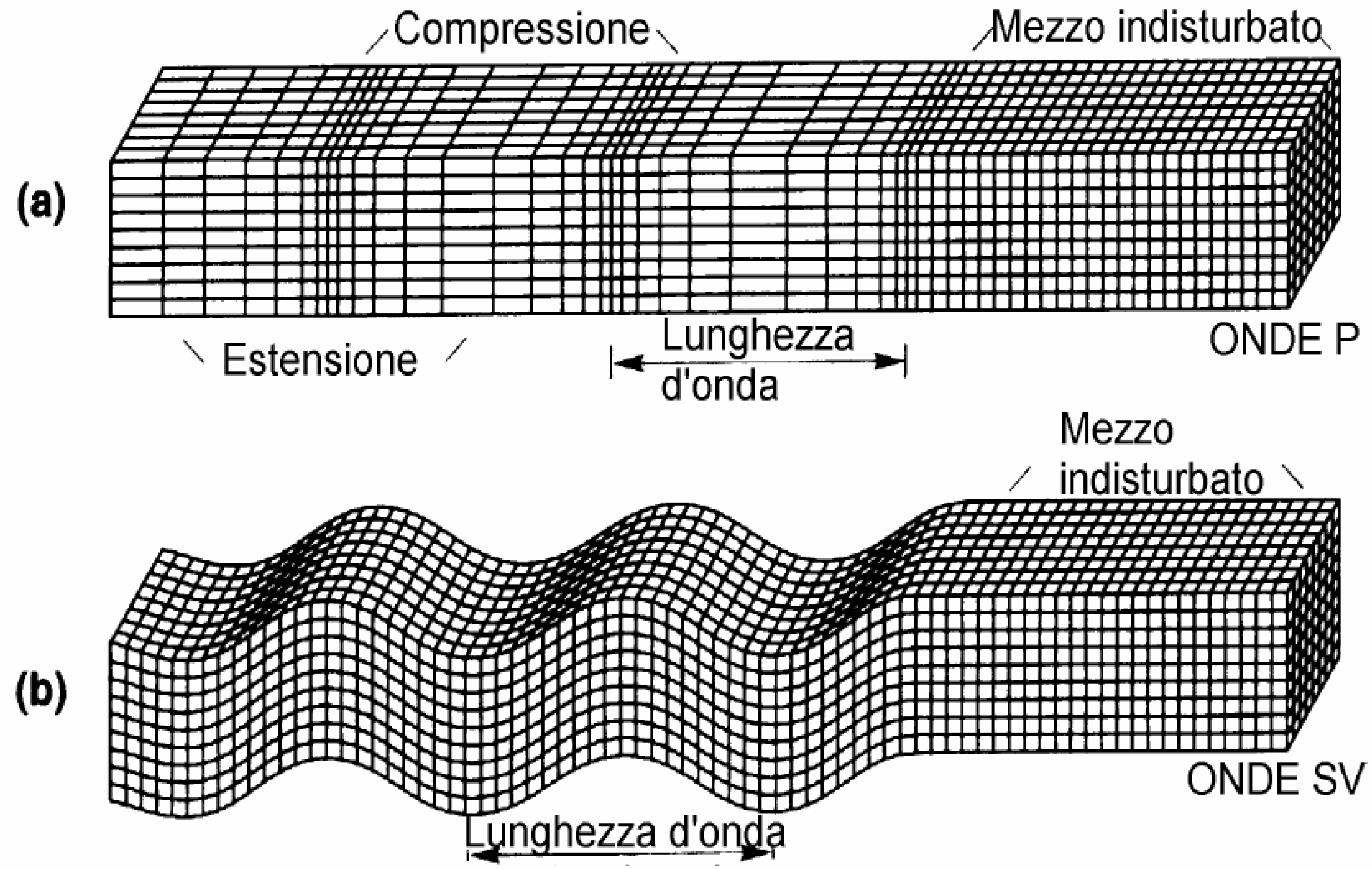
Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

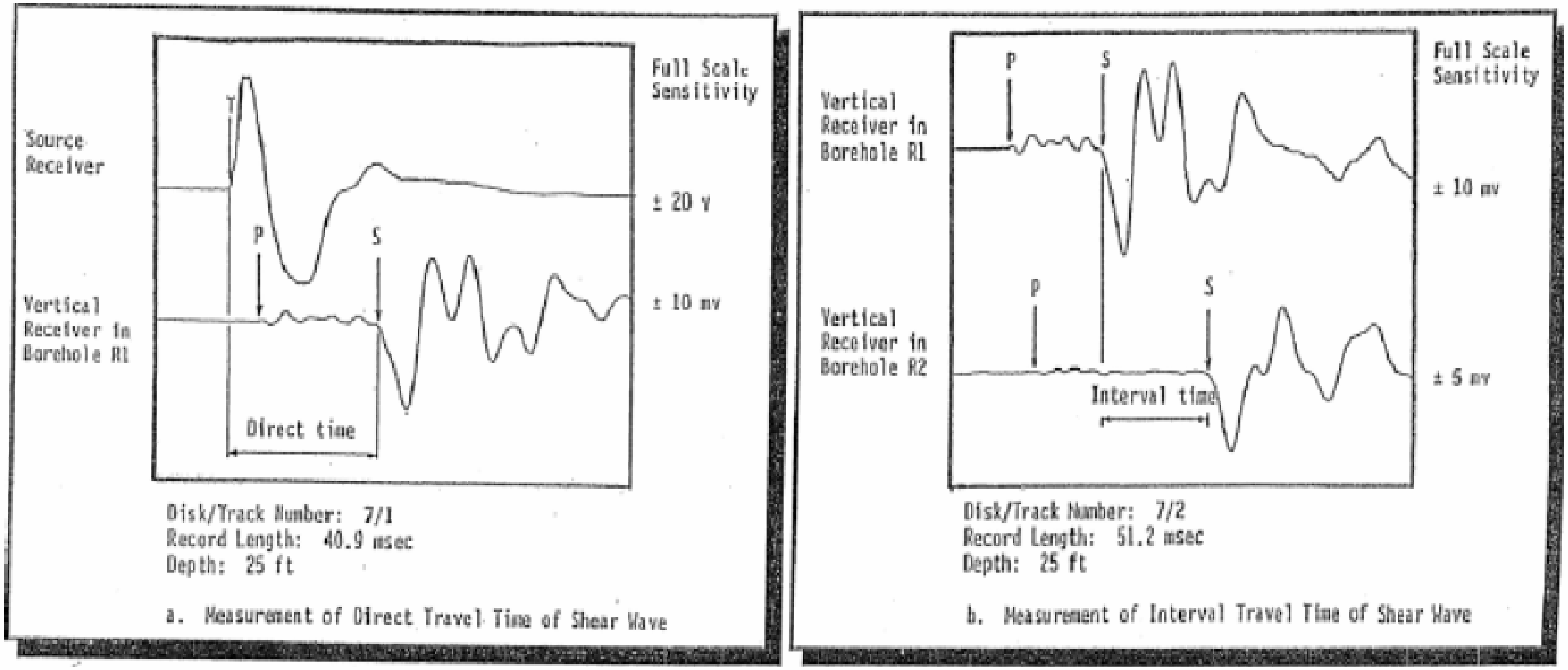
SCPTU INTERPRETATION

Body waves (Bolt 1988)



ARRIVAL TIME PICKUP

Test interpretation (one or two – Stokoe 1992)



a. Measurement of Direct Travel Time of Shear Wave

b. Measurement of Interval Travel Time of Shear Wave

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

HOMOGENEOUS – ELASTIC – ISOTROPIC MEDIUM

PROPAGATION VELOCITIES

$$V_s = d/t_s \qquad V_p = d/t_p \qquad V_R = f(\omega) = \lambda f$$

ELASTIC PARAMETERS

$$G_0 = \rho V_s^2 \qquad M_0 = \rho V_p^2 \qquad V_R / V_s \cong (0.862 + 1.14\upsilon) / (1+\upsilon)$$

$$\upsilon = (V_p^2 - 2V_s^2) / 2(V_p^2 - V_s^2)$$

$$\gamma = \frac{u_s}{V_s}$$

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

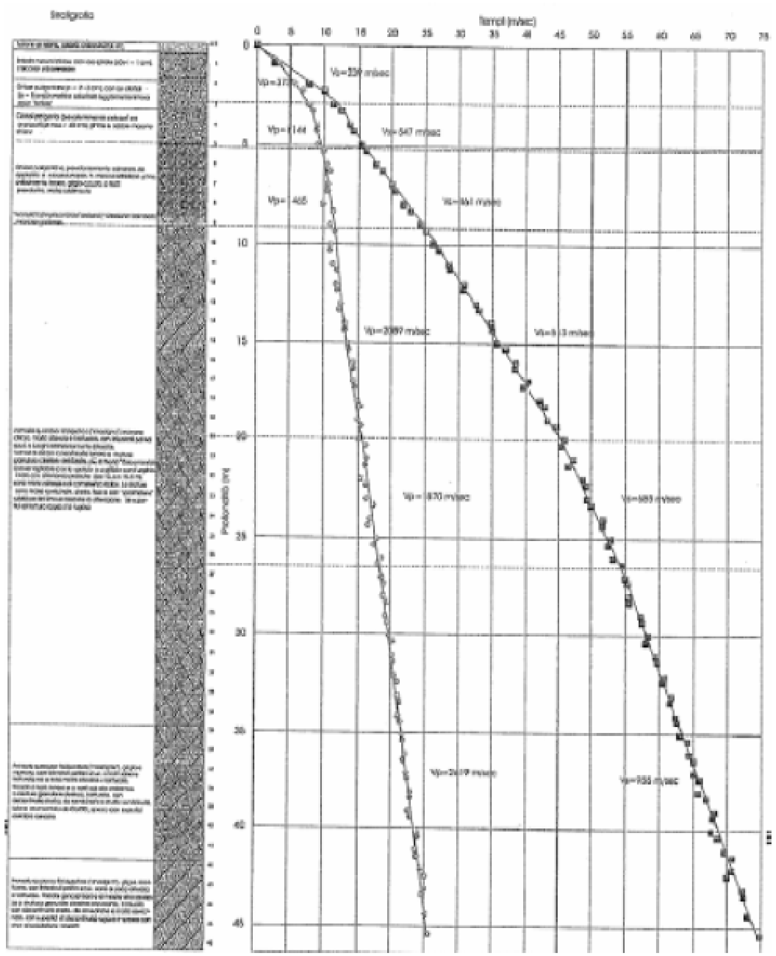
IN SUPREMÆ DIGNITATIS 1343

INTERPRETATION METHODS

- ARRIVAL TIME PICKUP
  - PSEUDO – INTERVAL
  - TRUE INTERVAL
- CROSS CORRELATION

CORRECTED-TIME VS. DEPTH

Pseudo - interval



USE OF Vp IN PARTIALLY SATURATED SOILS

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

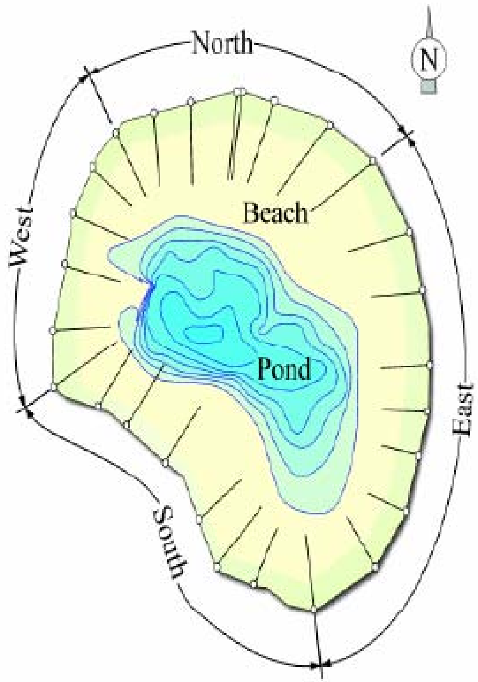
IN SUPREMÆ DIGNITATIS 1343

ANY REASON TO MESURE Vp?

CPTU and Vp measurements

Figure 1. Location of the Zelazny Most depository.

Maximum dam height:	63 m
Total volume stored:	527×10^6 m^3
Storage rate:	≥ 17.5×10^6 m^3/annum
Area covered:	12.4 km^2
Total length of dam:	14.3 km



Dams Height, m	
North:	39
West:	49
South:	34
East:	63

Crest Elev., m asl	
North:	177.5
West:	177.5
South:	177.0
East:	177.5

JAMIOLKOWSKI 2013 – RANKINE LECTURE

U2 from CPTU

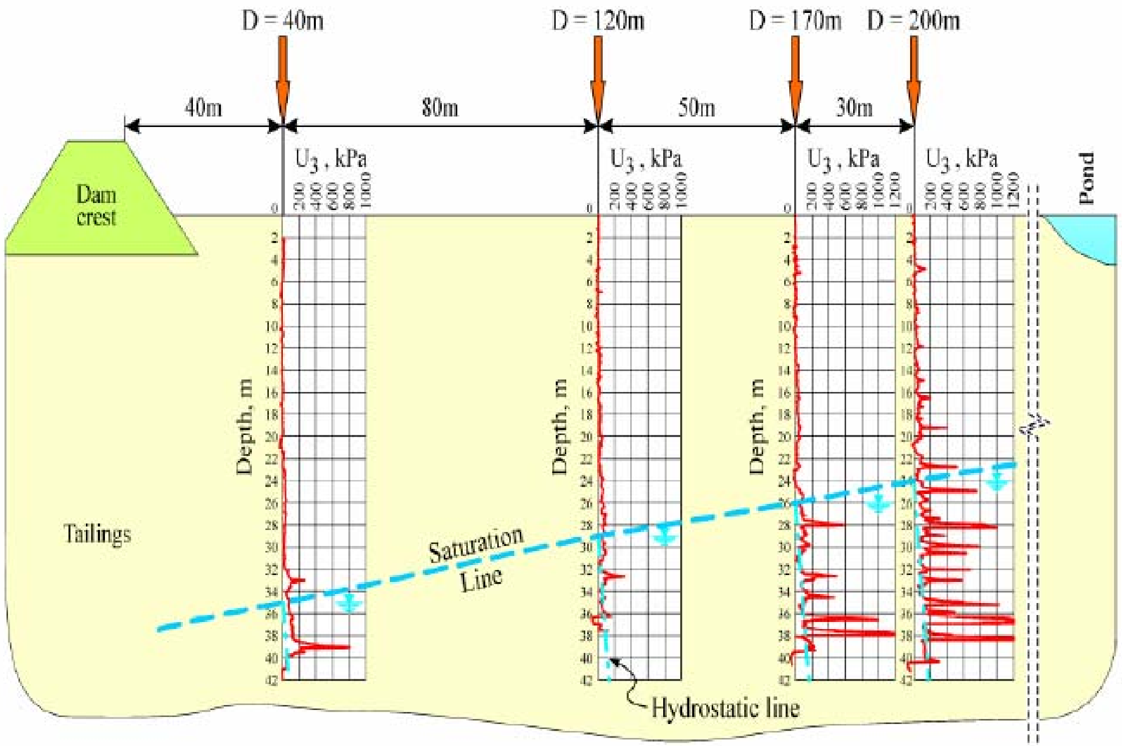


Figure 9. West Dam - Penetration pore pressure from CPTU.

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

JAMIOLKOWSKI 2013 – RANKINE LECTURE

Vp from down hole measurements

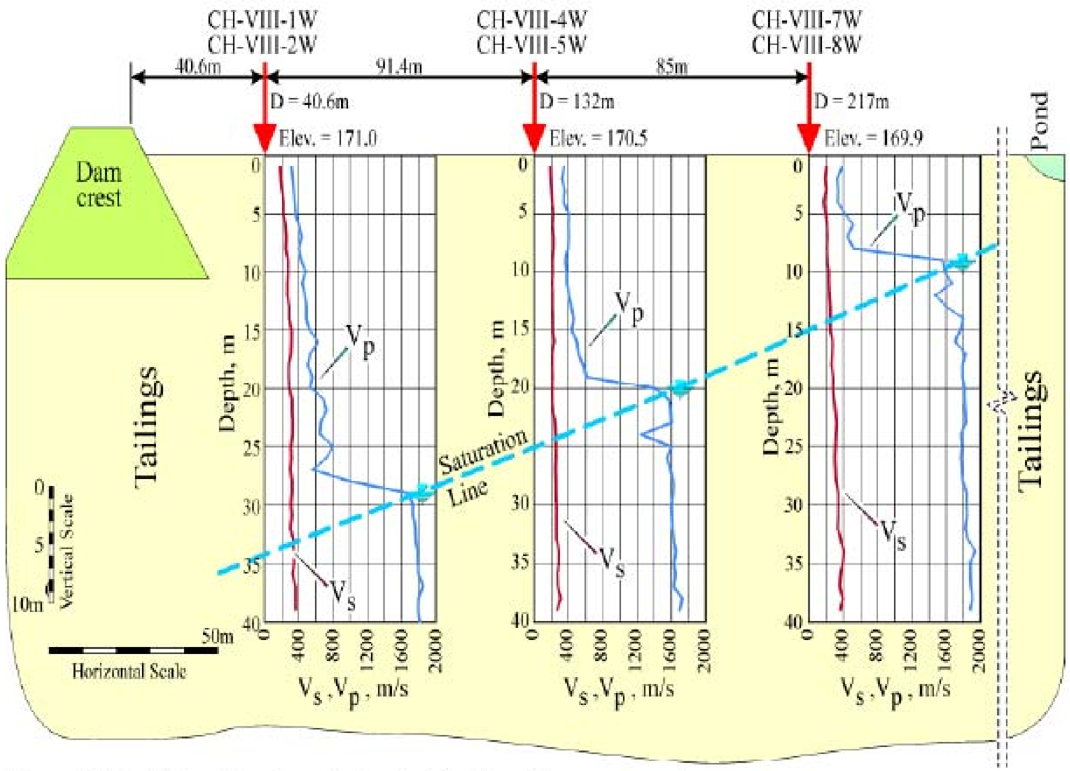


Figure 12. West Dam - Location of saturation line from V_p measurements.

Ordine dei Geologi della Toscana

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

CC TESTS ON TICINO SAND 1

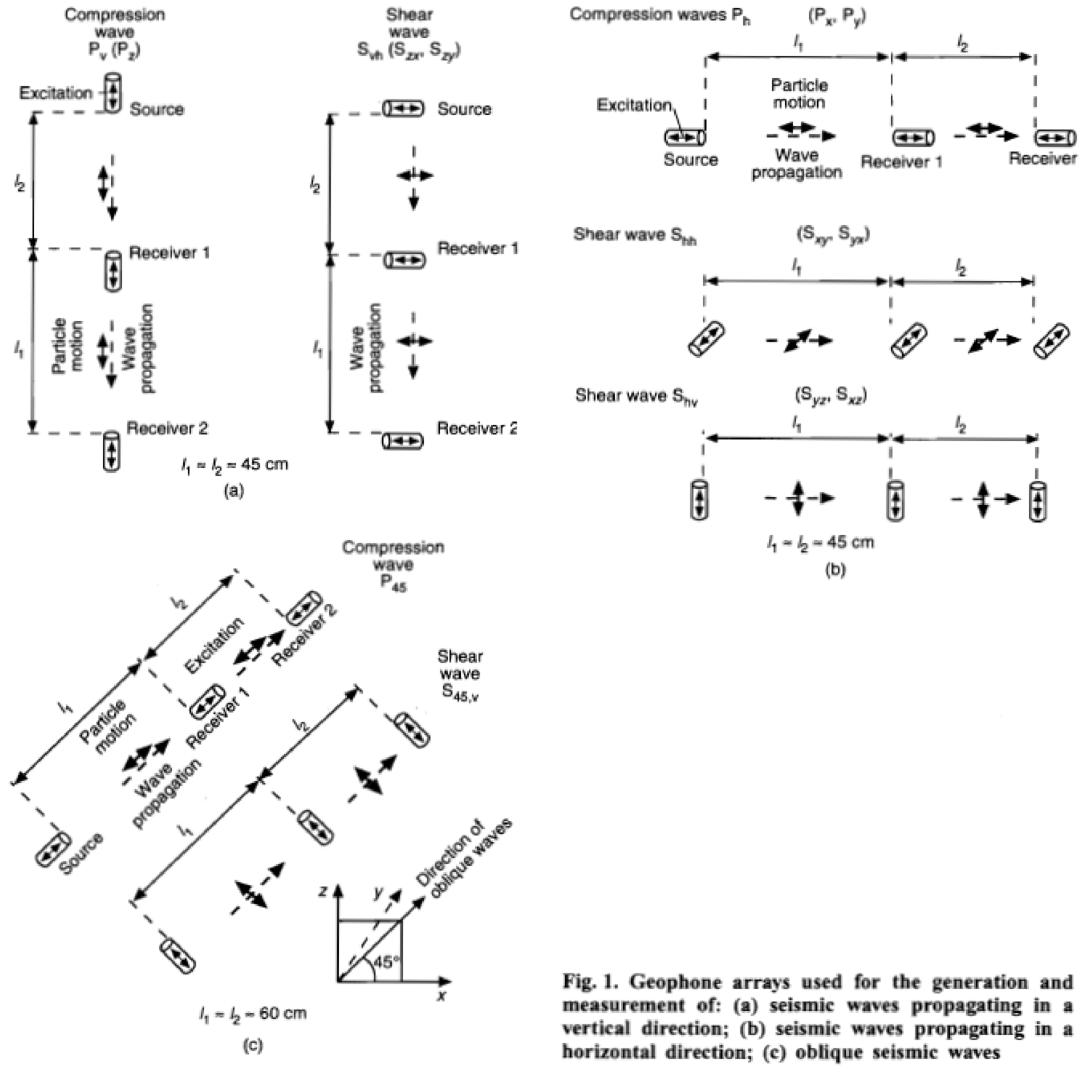


Fig. 1. Geophone arrays used for the generation and measurement of: (a) seismic waves propagating in a vertical direction; (b) seismic waves propagating in a horizontal direction; (c) oblique seismic waves

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

CC TESTS ON TICINO SAND 2

$$V_s = C_s \sqrt{[F(e)(\sigma'_a)^{na}(\sigma'_b)^{nb}(\sigma'_c)^{nc}]} \quad (3)$$

$$V_p = C_p \sqrt{[F(e)(\sigma'_a)^{na}(\sigma'_b)^{nb}(\sigma'_c)^{nc}]} \quad (4)$$

$$G_0 = C_G F(e) p_a^{(1-2na-2nb-2nc)} (\sigma'_a)^{2na} \times (\sigma'_b)^{2nb} (\sigma'_c)^{2nc} \quad (5)$$

$$M_0 = C_M F(e) p_a^{(1-2na-2nb-2nc)} (\sigma'_a)^{2na} \times (\sigma'_b)^{2nb} (\sigma'_c)^{2nc} \quad (6)$$

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

INHERENT ANISOTROPY

	Wave	$C_p \sqrt{F(e)}$	$na + nb$	R^2	N
○	P_v	132	0·243	0·978	88
□	P_h*	157	0·235	0·980	88

*Includes P_x and P_y waves

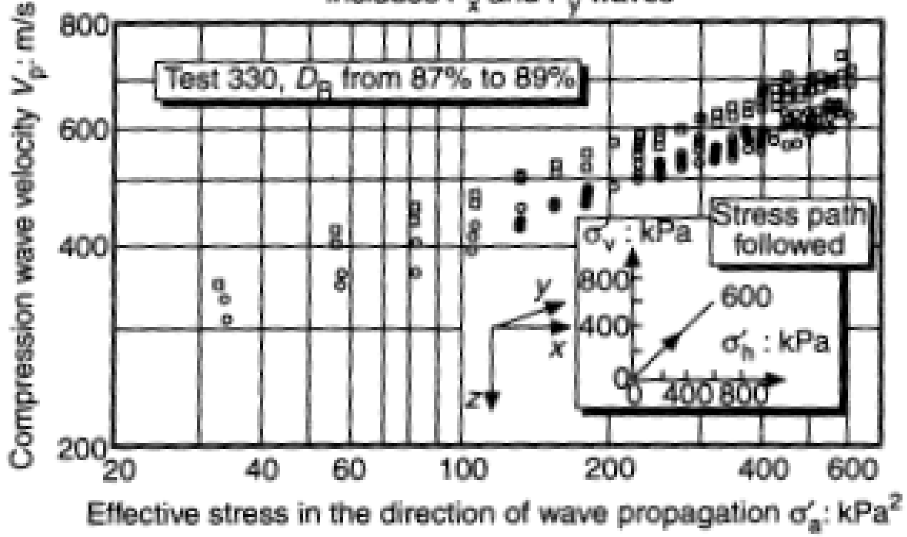
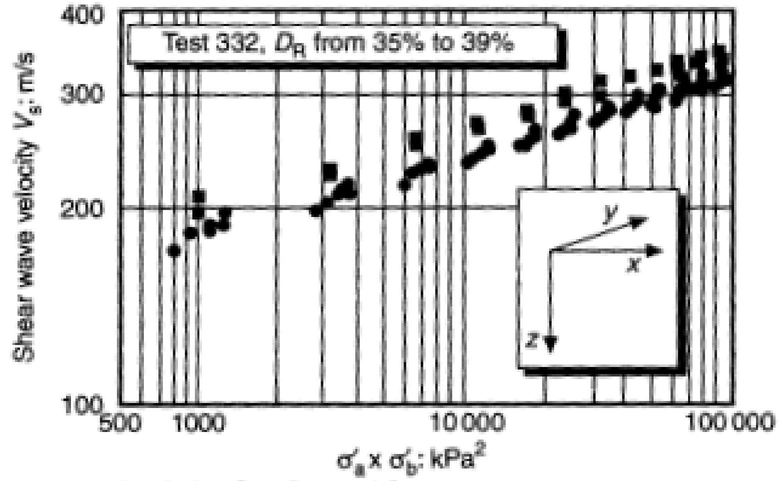


Fig. 9. Velocity of compression waves in an isotropically consolidated specimen

	Wave	$C_p \sqrt{F(e)}$	$na + nb$	R^2	N
●	S_{vh}, S_{hv}*	79	0·121	0·990	72
■	S_{vh}†	91	0·116	0·989	24

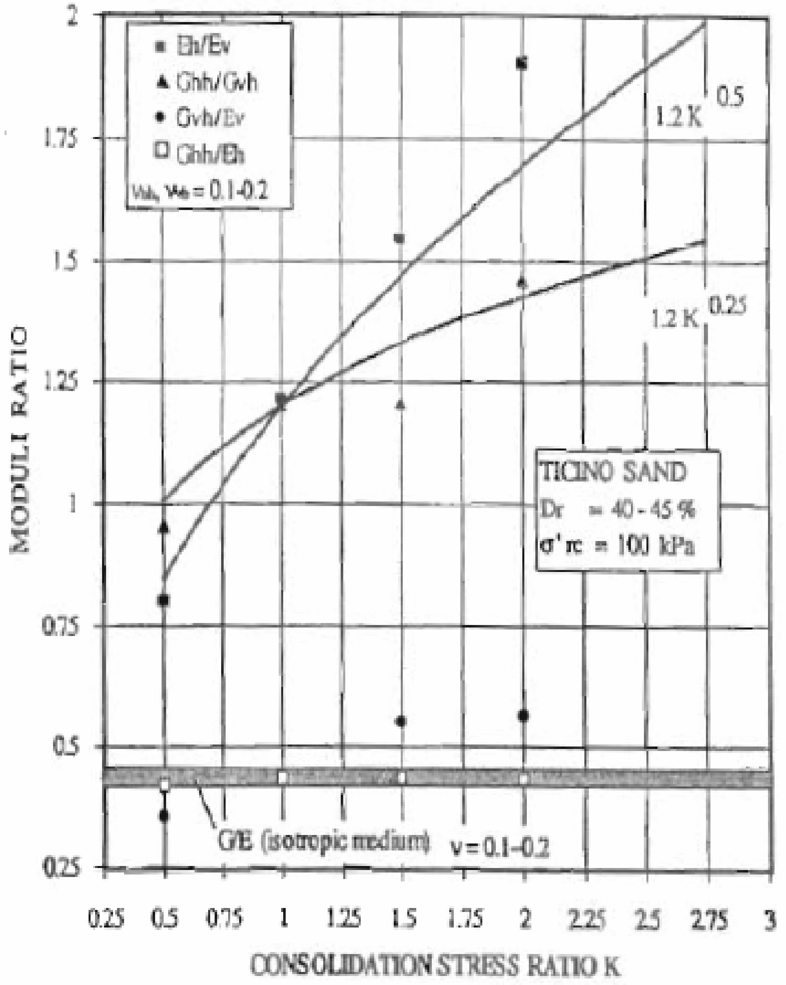


*Includes S_{zx}, S_{zy} and S_{yz} waves

†Includes S_{xy}, S_{yx} waves

Fig. 10. Velocity of shear waves in an isotropically consolidated specimen

STRESS-INDUCED ANISOTROPY



E_v = Young's modulus in the vertical direction

E_h = Young's modulus in the horizontal direction

ν_{vh} = Poisson's ratio for effect of the vertical stress on the horizontal strain

ν_{hh} = Poisson's ratio for effect of the horizontal stress on complementary horizontal strain

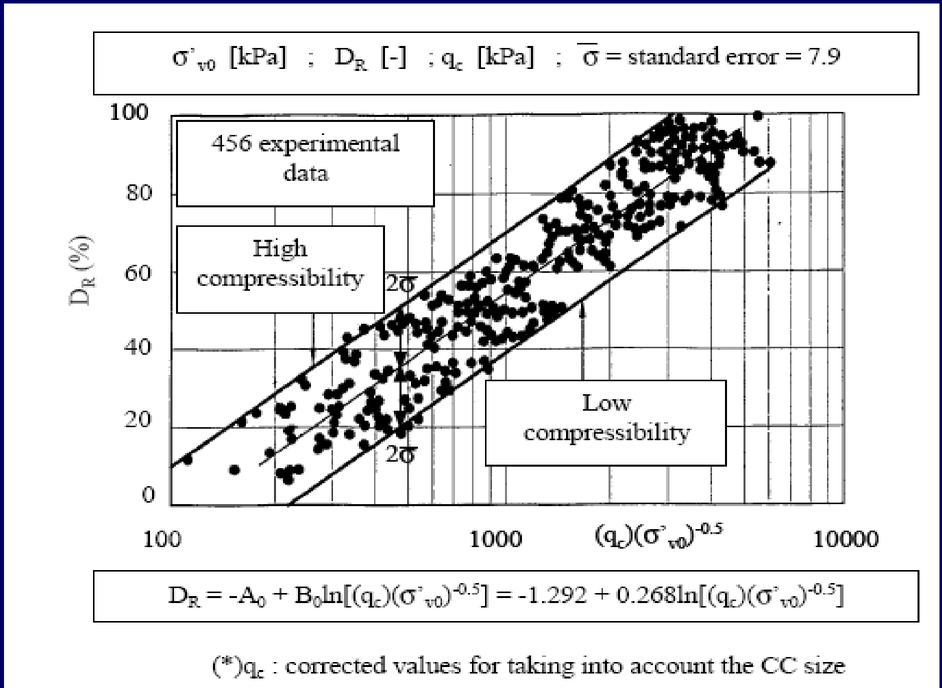
G_{vh} = shear modulus referred to the vertical plane.

EFFECTS OF SATURATION ON SANDS

- CC DATA S=0% OR S=100% (FINE TO MEDIUM SANDS)
- NEGLIGIBLE EFFECTS (BELLOTTI ET AL. 1988 ISOPT I; SCHMERTMANN 1976, JAMIOLKOWSKI ET AL. 2001)

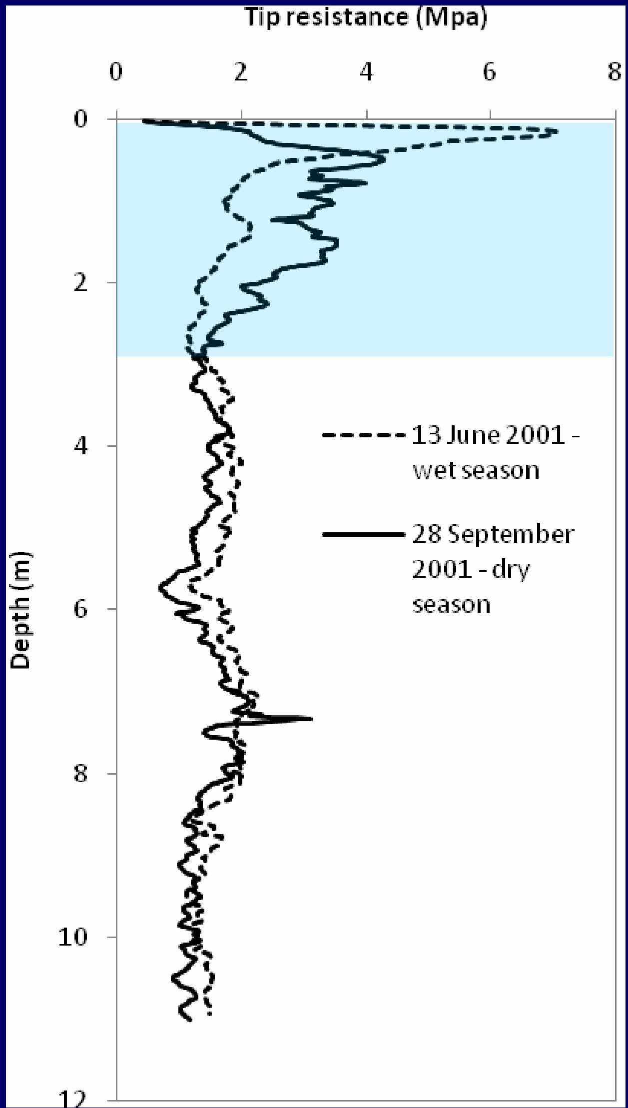
EFFECTS OF SATURATION ON SANDS

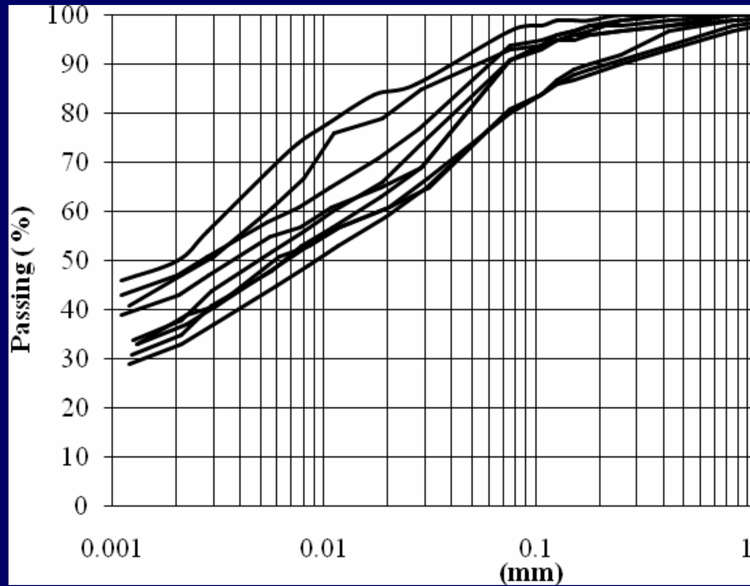
- JAMIOLKOWSKI ET AL. 2001 (UNDERESTIMATE 7 – 10%)

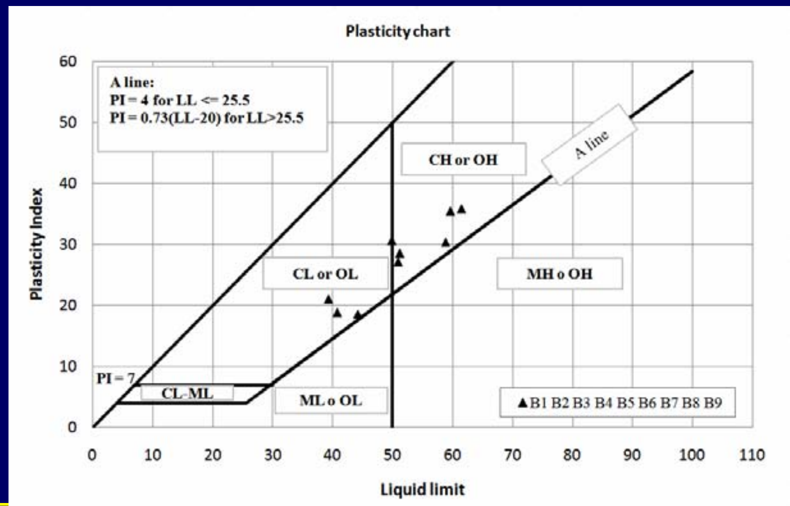


$$\frac{D_R\,(\text{saturated}) - D_R\,(\text{dry})}{D_R\,(\text{dry})} 100 = -1.87 + 2.32 \ln \frac{q_c}{(\sigma'_{vo} p_a)^{0.5}}$$

PARTIALLY SATURATED FINE GRAINED SOILS - BRONI







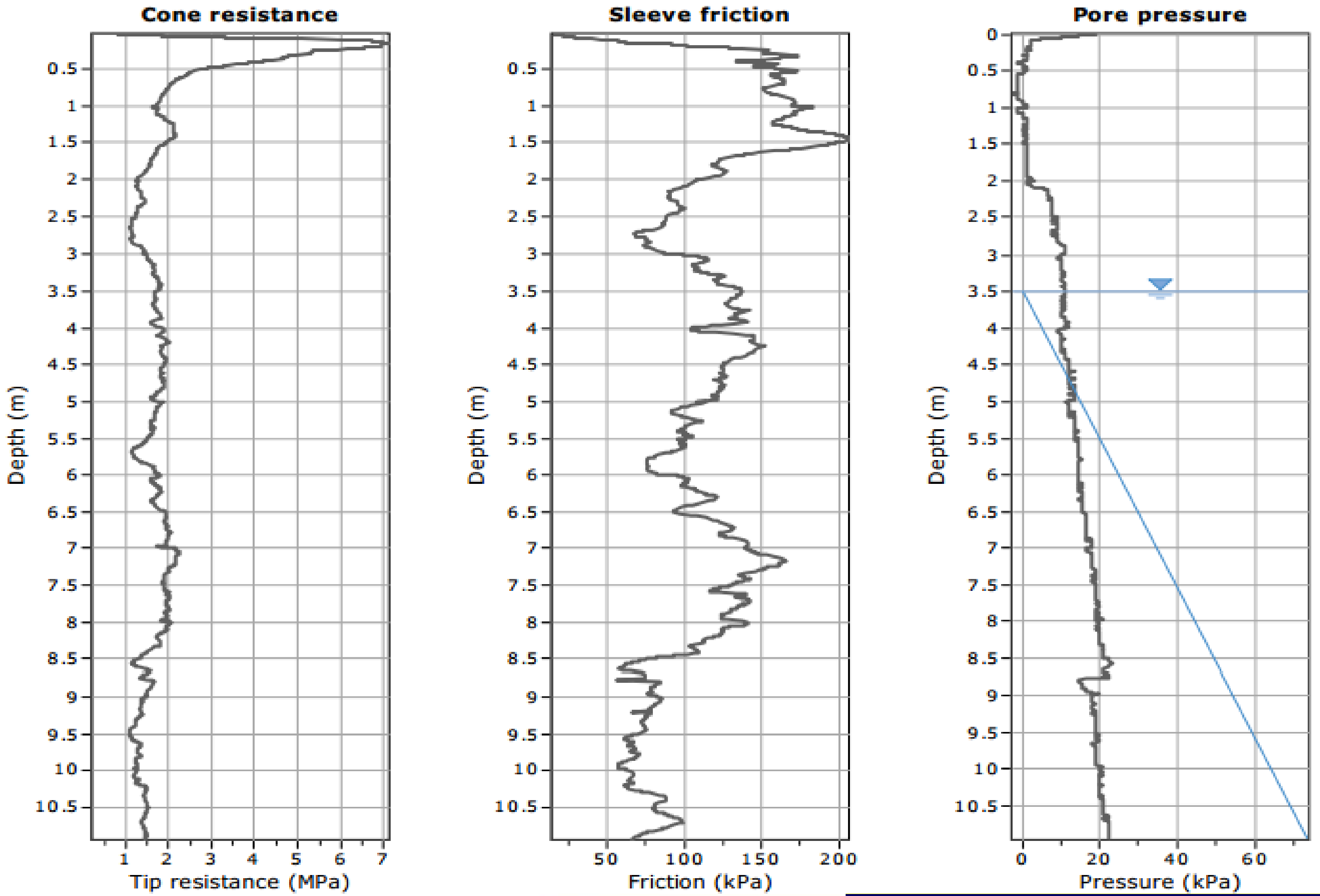
L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

CPTu1 TEST CONDUCTED DURING THE WET SEASON (BRONI).



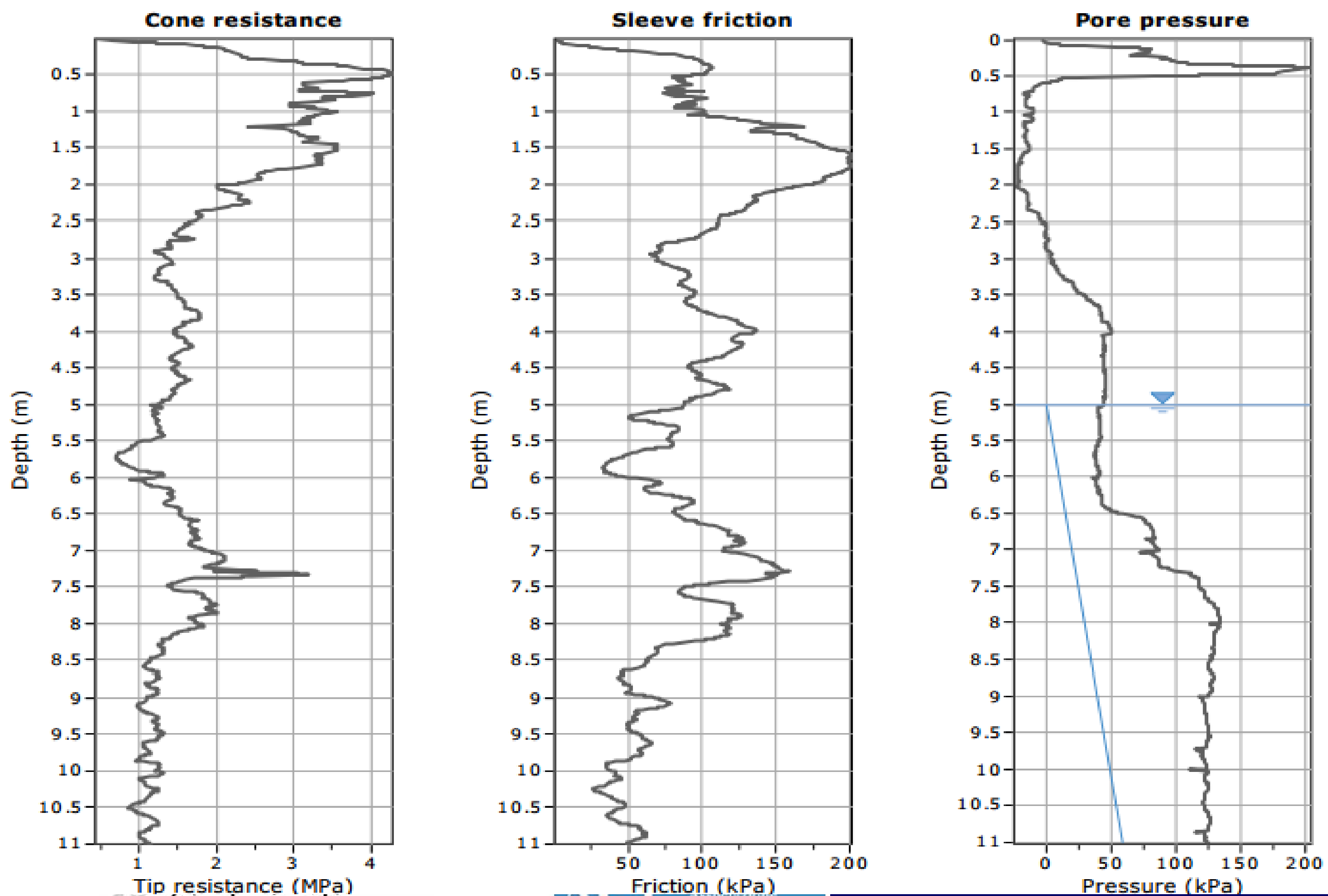
Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

IN SUPREMÆ DIGNITATIS 1343

CPTu2 TEST CONDUCTED DURING THE DRY SEASON (BRONI).



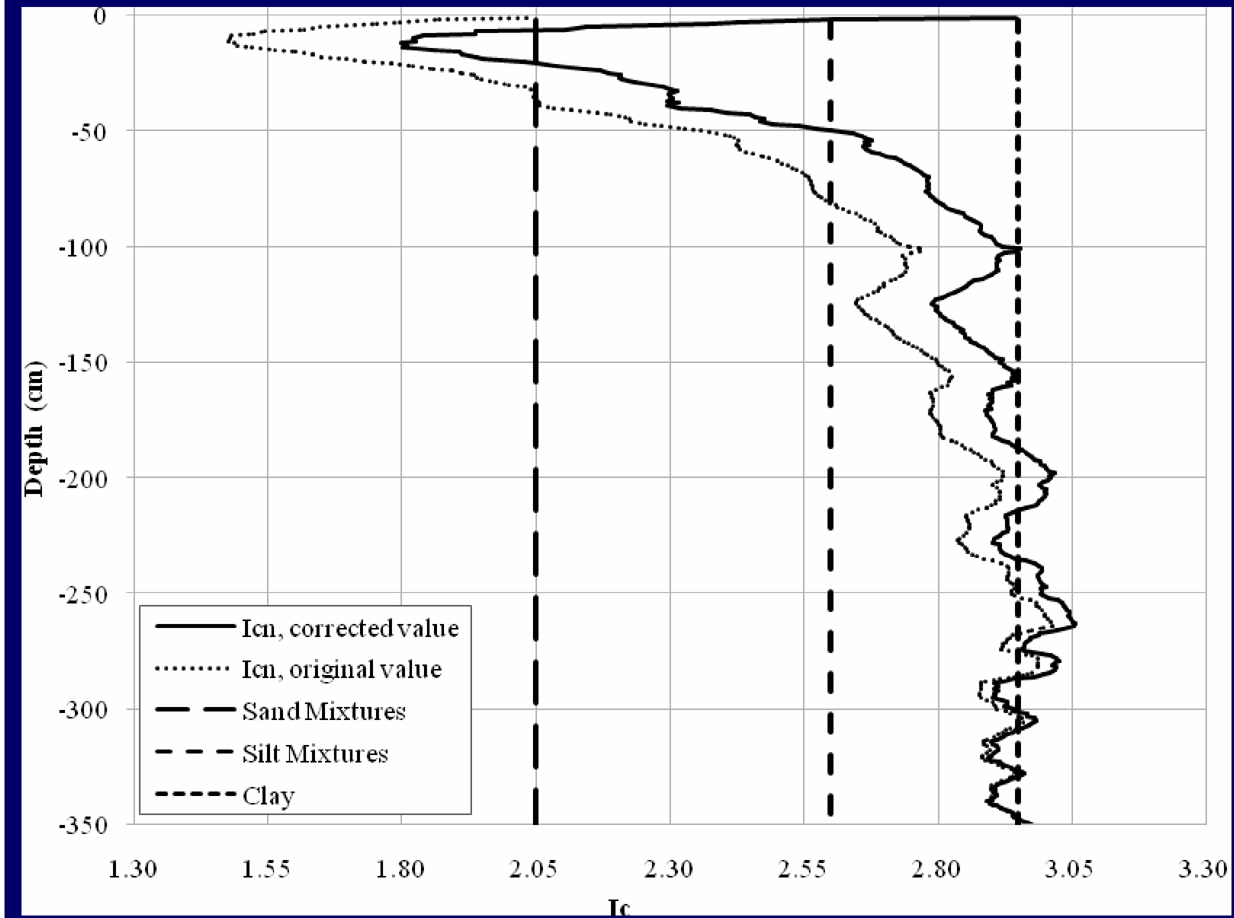
L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

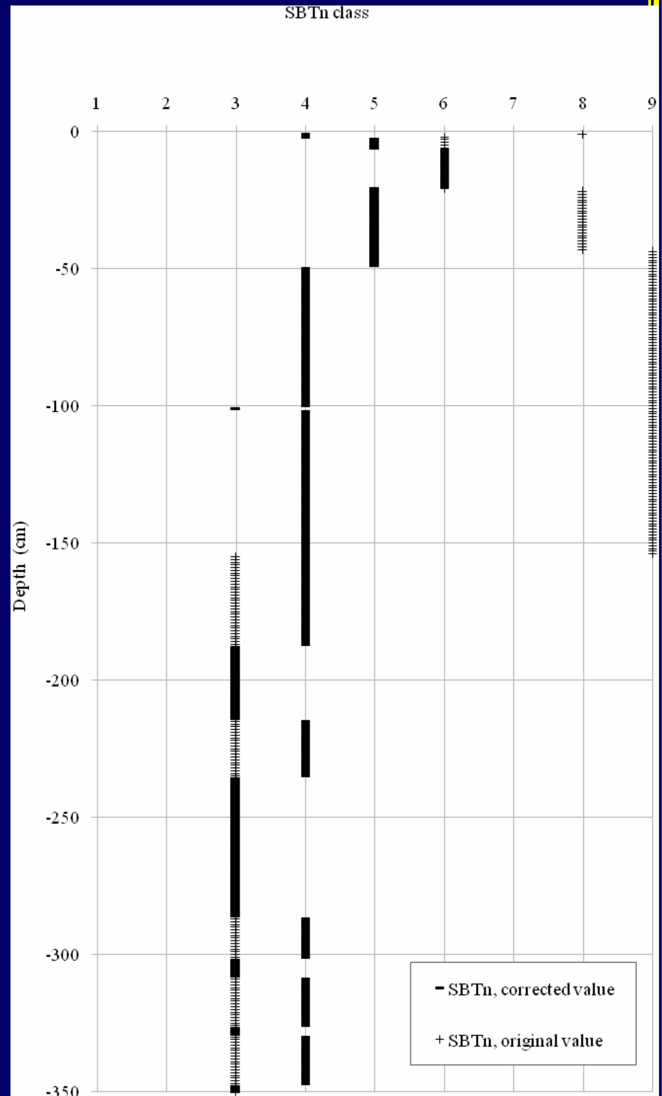
Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

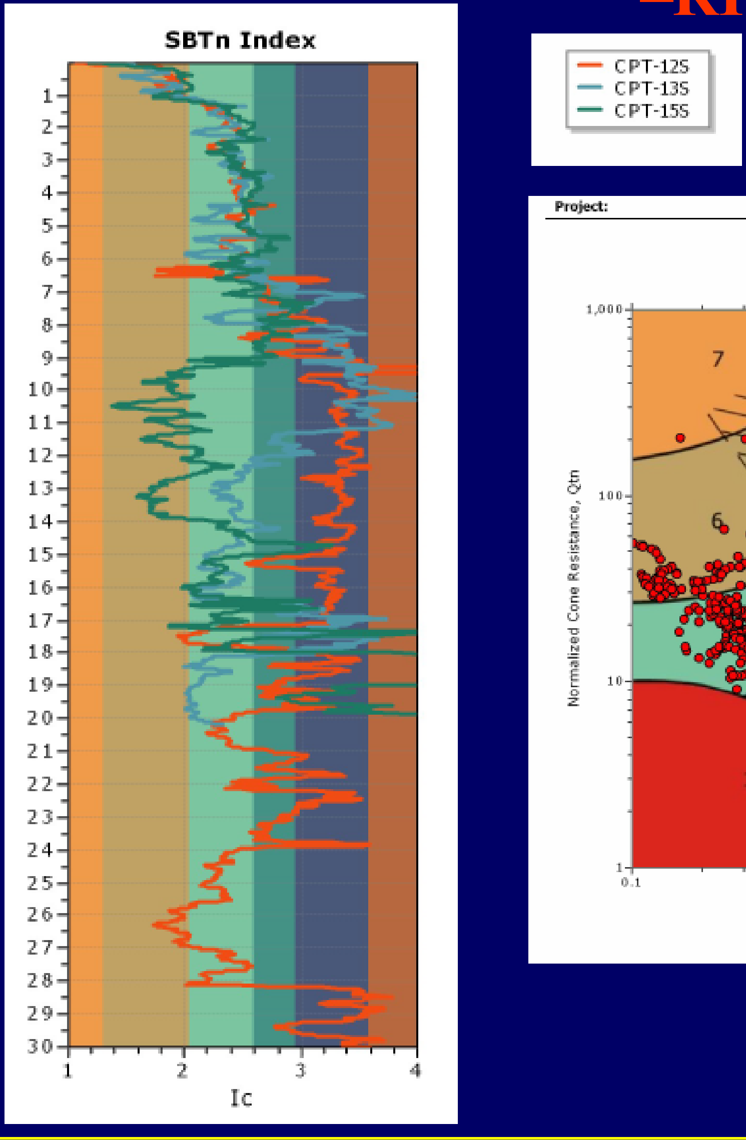
MISS CLASSFICATION AT BRONI

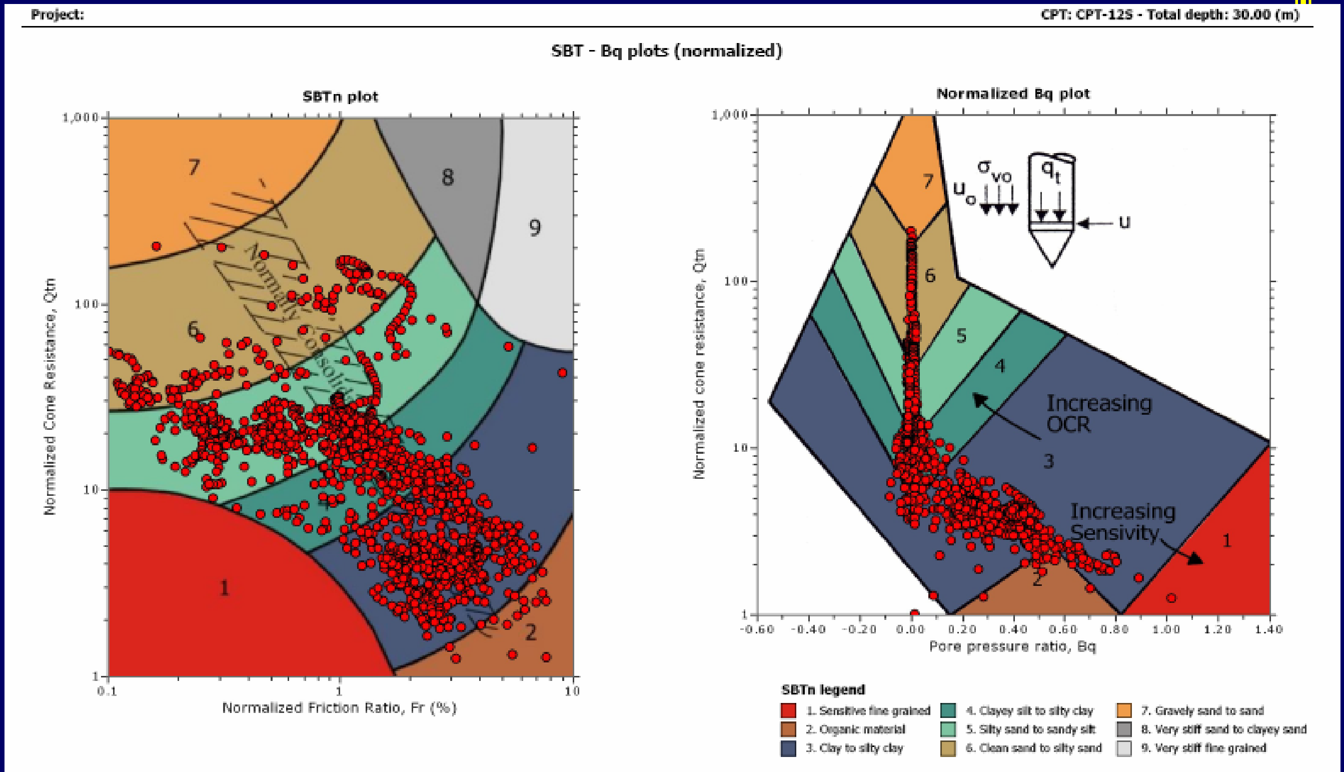




L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA
Ordine dei Geologi della Toscana
AGI Associazione Geotecnica Italiana
IN SUPREMÆ DIGNITATIS 1343

MISS – CLASSFICATION: LOOSE SILTY SOILS (SERCHIO –RIVER LEVVES)





MK MODEL

- Kovacs (1981) and Aubertin, et al. (2002). The MK model has been used to evaluate, from simple soil parameters, the matrix suction (ψ_r) at the residual water content and the equivalent capillary height above the water table (h_{co}).
- (Aubertin et al. 1998; Mbonimpa et al. 2000, 2002).

EQUATIONS

- For clayey soil

$$\psi_r = 0.86\left(\frac{\xi}{e}\right)^{1.2} w_L^{1.74}$$

- (ρ_s = dry density)

$$\xi\,(cm) \approx 0.15\rho_s\,(kg/m^3)$$

$$u = -\gamma_w \cdot h \qquad for\ \ 0 < h < h_{c0}$$

$$u = -\gamma_w \cdot h_{c0} \qquad for\ h > h_{c0}$$

EFFEECTS OF EFFECTIVE STRESS ON Ic

$$I_c = \sqrt{(3.47 - \log Q_{tn})^2 + (\log F + 1.22)^2}$$

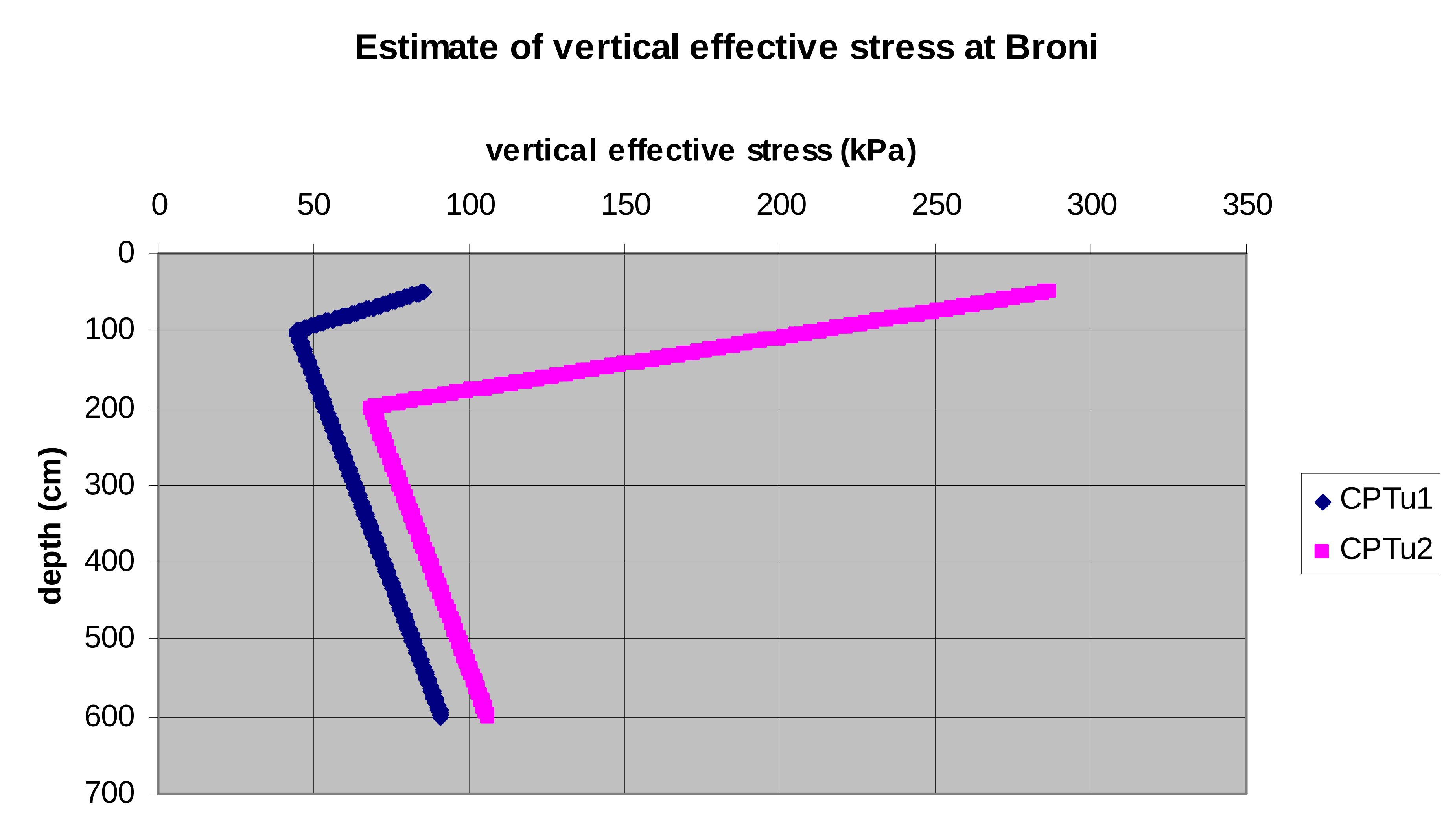
$$Q_{tn} = \left(\frac{q_t - \sigma_{v0}}{\sigma_{atm}}\right)\left(\frac{\sigma_{atm}}{\sigma'_{v0}}\right)^n;$$

$$F = \frac{f_s}{q_t - \sigma_{v0}} \cdot 100;$$

$$n = 0.381 \cdot I_c + 0.05 \cdot \left(\frac{\sigma'_{v0}}{\sigma_{atm}}\right) - 0.15$$

Soil classification (SBTn)	Zone number (Robertson SBT 1990)	SBT Index values
Organic soils: peats	2	$I_c > 3.60$
Clays: silty clay to clay	3	$2.95 < I_c < 3.60$
Silt Mixtures: clayey silt to silty clay	4	$2.60 < I_c < 2.95$
Sand Mixtures: silty sand to sandy silt	5	$2.05 < I_c < 2.60$
Sands: clean sand to silty sand	6	$1.31 < I_c < 2.05$
Gravelly sand to dense sand	7	$I_c < 1.31$

MODIFICATION OF THE VERTICAL EFFECTIVE STRESS TO GET A CONSTANT Ic (BRONI)

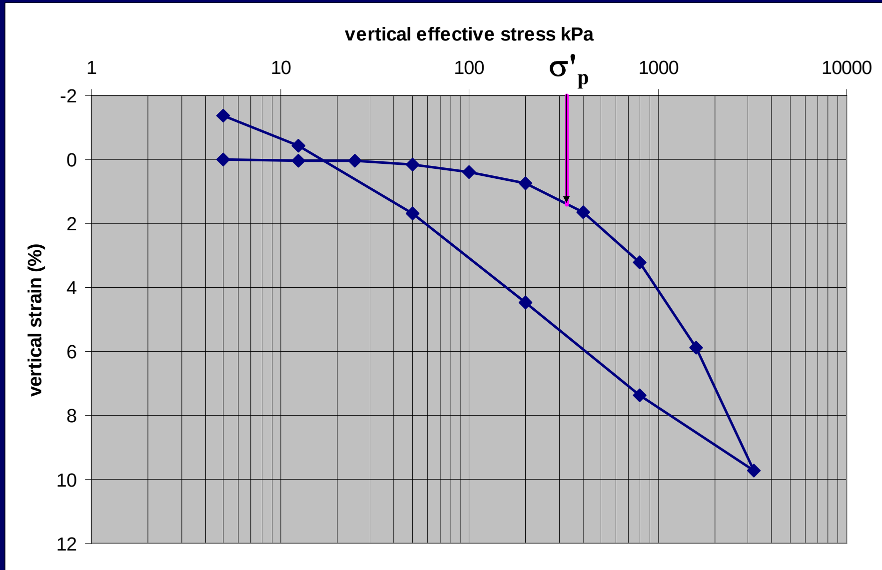


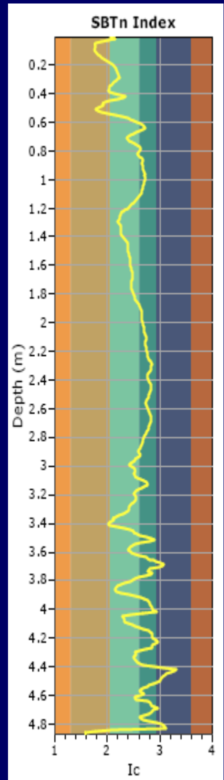
Associazione Geotecnica Italiana

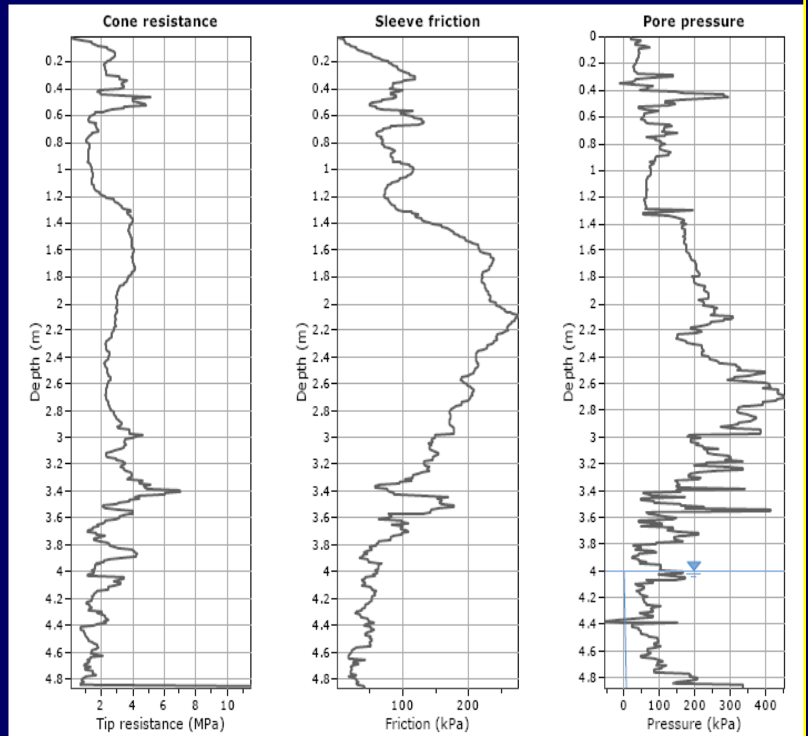
PRACTICAL MEANING OF THE CORRECTION

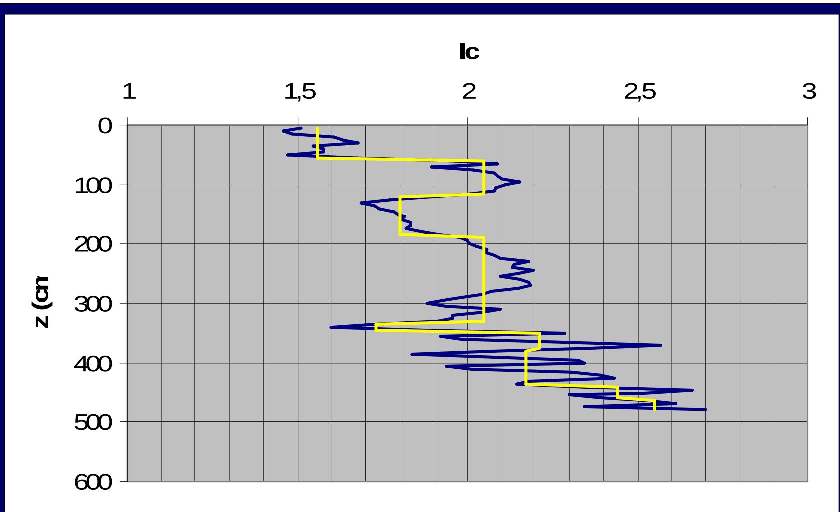
- THE SBT INTERPRETATION COULD GIVE AN ASSESSMENT OF THE EFFECTIVE STRESS-STATE
- MODIFYING A SBT INTERPRETATION INTO A “SOIL TYPE” INTERPRETATION, THE DIFFERENCES IN Ic SHOULD REFLECT WHAT IS MISSING IN “SOIL TYPE” INTERPRETATION (i.e.OCR)

POSSIBLE IDENTIFICATION OF PRECONSOLIDATION PRESSURE (PORCARI LUCCA)









Preconsolidation pressure
From oedometer: 320 – 476 kPa
From CPTu: 296 kPa

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

EMPIRICAL CORRECTION

- Define Ic from borehole data (grain size curve)
- The new classification system is not SBT but depends on texture
- Criteria:
  - AGI 1997
  - Example: Silt with clay (2.6<Ic<2.95)

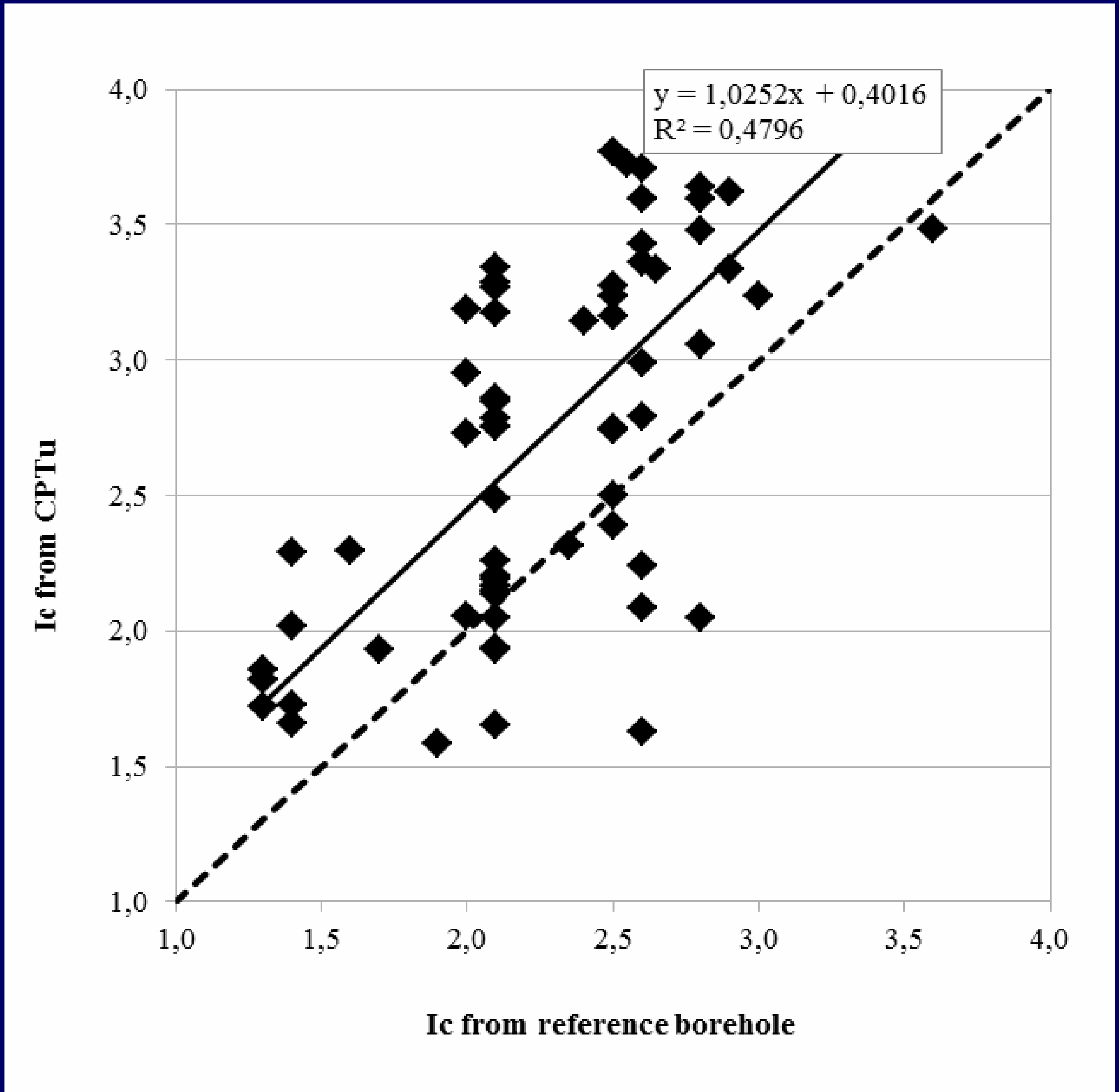
ASSESSMENT OF Ic FROM BOREHOLE

Borehole #	Soil classification from borehole (AGI 1997)	Ic from borehole	Ic from CPTu	ΔIc	SBTn	Soil classification from CPTu
1	Clayey and sandy silt	2.60	2.79	0.19	4	Sand Mixtures
	Silty sand	2.10	2.05	-0.05	6	Sand
	Silty sand	2.10	2.49	0.39	5	Sand Mixtures
	Sand, gravel and fine gravel	1.30	1.72	0.42	6	Sand
	Silty sand	2.10	2.19	0.09	5	Sand Mixtures

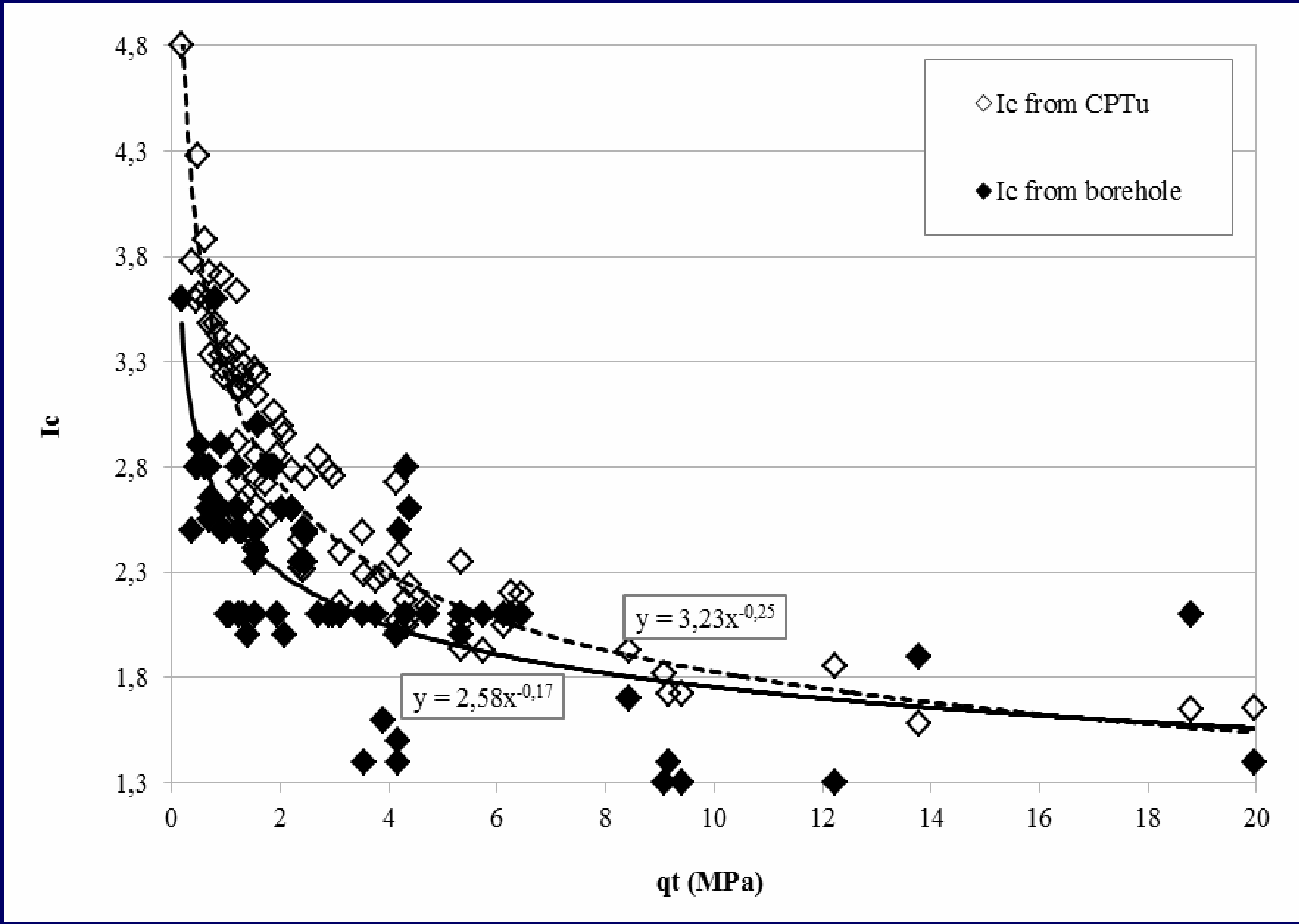
DATABASE

- SERCHIO RIVER LEVEE SYSTEM AND FOUNDATION SOIL
- DREDGED SEDIMENTS IN ARTICICIAL BASINS (PORT OF LIVORNO)

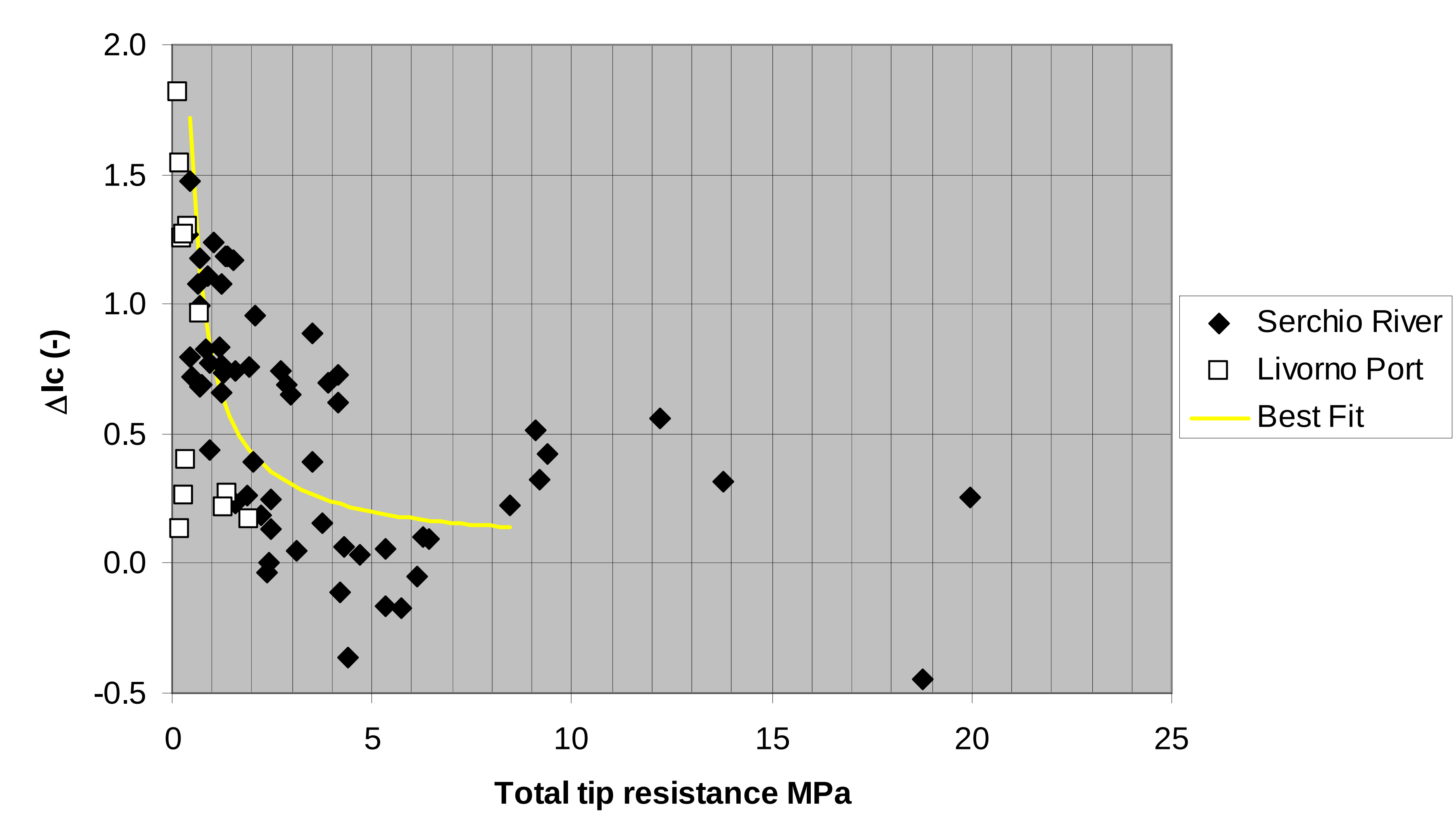
Ic FROM BOREHOLES AND CPTu



HOW TO CORRECT



ΔIc FUNCTION



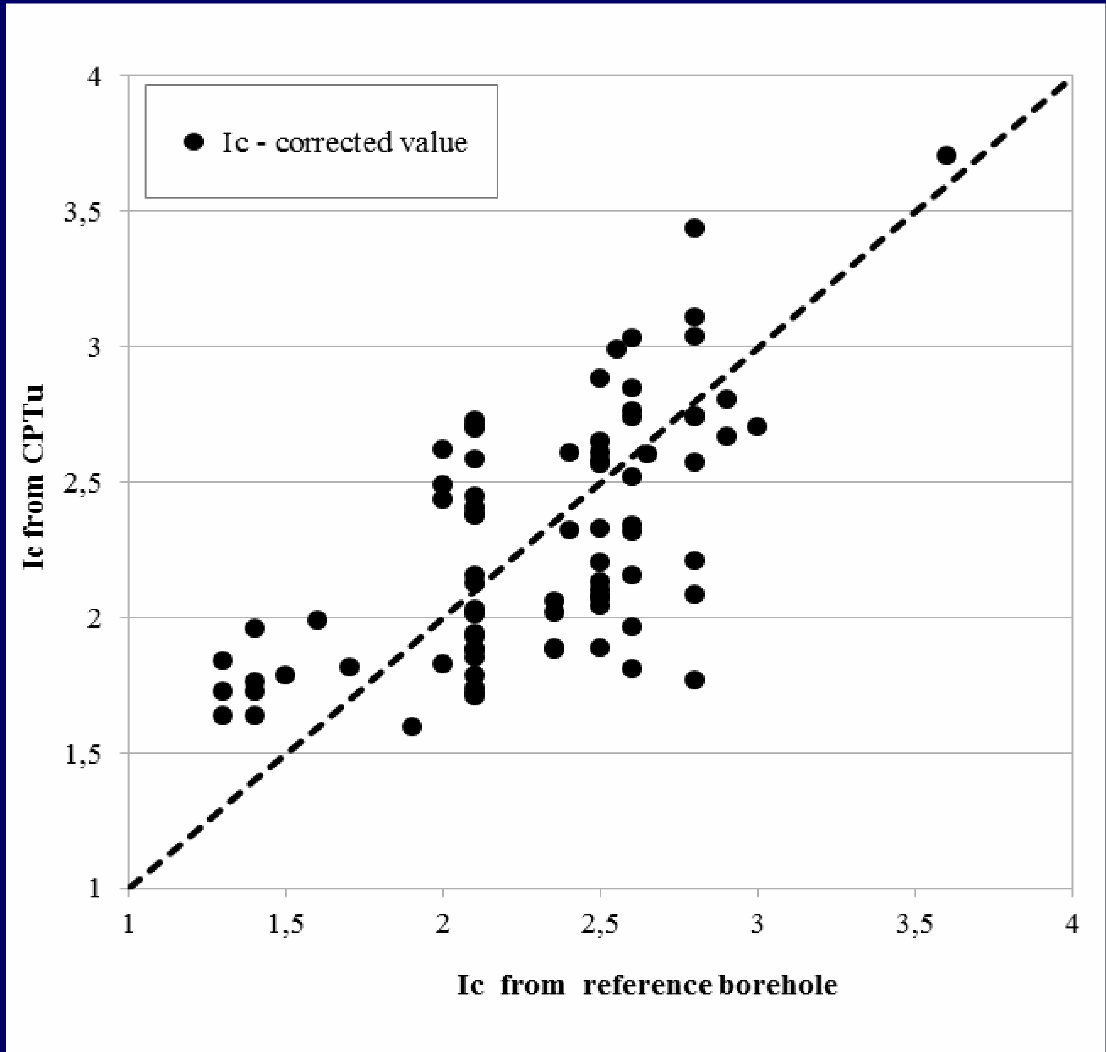
L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

Ic AFTER CORRECTION



L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343

ACKNOLEDGEMENTS

- DATA HAVE BEEN MADE AVAILABLE BY PROF. C. MEISINA (UNIPV), DR. BARSANTI (GEOPROVE - LUCCA), DR. COSCO & SPADARO (GEOSERVIZI- PISA).
- THE HELP GIVEN BY THE FOLLOWING STUDENTS IS ALSO ACKNOWLEDGED:
- M. ROSIGNOLI, N. FULCINITI, M. MARCONCINI, D.BUSONI, M. PONZANELLI, A. SCARDIGLI, C. ZACCAGNINO

L'ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI PISA

Ordine dei Geologi della Toscana

AGI Associazione Geotecnica Italiana

IN SUPREMÆ DIGNITATIS 1343