WORKSHOP

Recenti Sviluppi nelle Indagini in Sito

Scuola di Ingegneria - Polo Etruria - Aula F1 - Pisa

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Thin layering and liquefaction

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OUTLOOK

CPT/CPTu as site characterization techniques

- Continuous measurements of soil parameters (qc, fs, u)
- Measurement repeatibility
- Possibility of investigating a soil volume greater than that of laboratory samples
- Large existing databases

- CPT/CPTu complementary tools for stratigraphic investigations
  - Lithotype identification (in terms of Soil Behavior Type SBT)
  - Identification of stratigraphic boundaries
  - Reconstruction of the stratigraphic profile
  - Stratigraphic correlations
  - CPT/CPTu measurements provided a high-resolution data set suitable for 3D modeling.

Significant efforts into procedure and equipment standardization

- International standards such as ASTM D5578 (1995), ASTM5778-12, 2012, ASTM D3441-16, 2016 and EN ISO 22476-1 (2012) define testing procedures, cone geometry and accuracy/repeatability requirements for testing with electric cone or piezocone.
- Well established cone penetration technologies
- Usually a cone with an apex angle of 60° and a tip cross-section of 10 or 15 cm^2 is recommended.

2. CHALLENGING ISSUES OF CPTU INTERPRETATION

Multiple thin layers

- **Intermediate soil deposits (complexity in data interpretation due to partial drainage) → Soil mixtures**

- **Alternation of soil mixtures**

- **Transition zones**

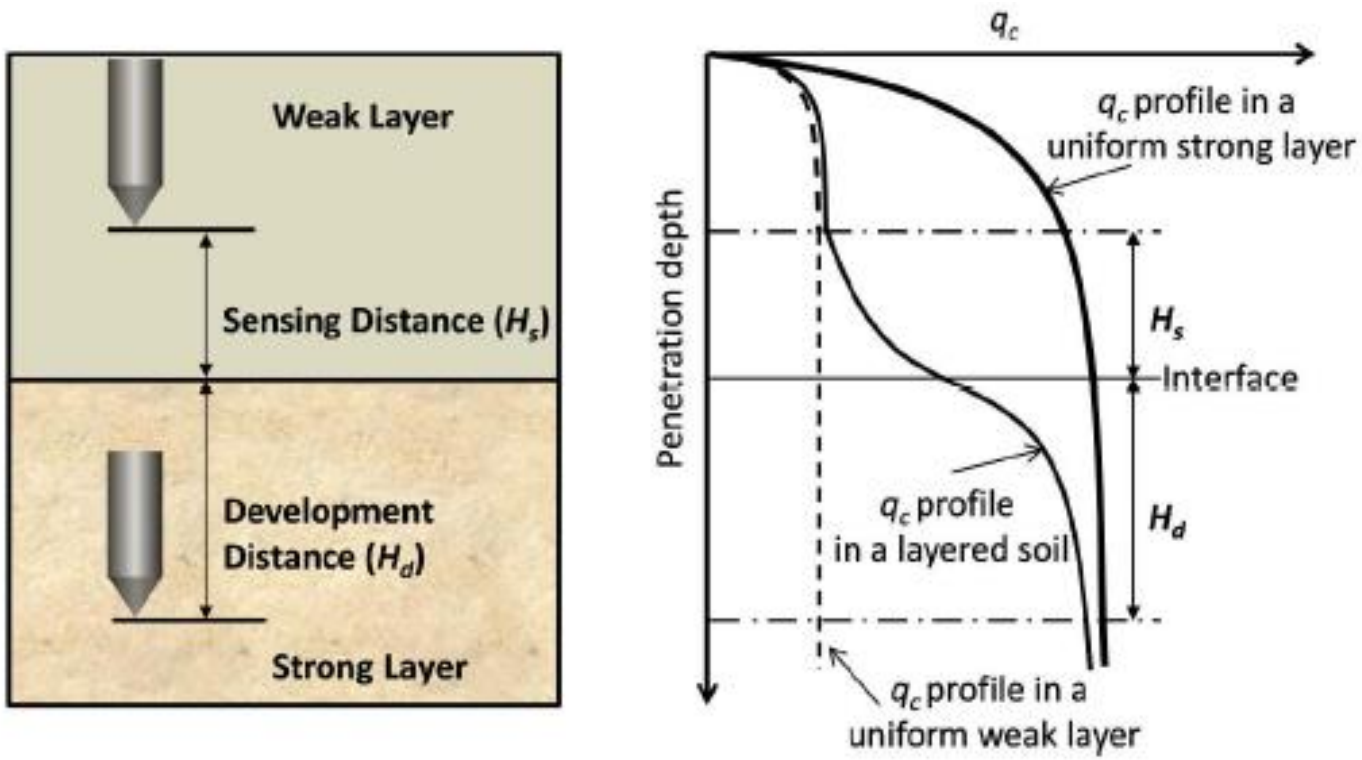
- **Thin layers identification (Van der Linden, 2017, Boulanger and De Jong, 2018; De Lange, 2018)**

2. CHALLENGING ISSUES OF CPTU INTERPRETATION

- the spatial resolution of cone tip resistance (qt) and sleeve friction (fs) measurements is still limited by the physical volume of soil around a cone tip that influences those measurements
- qt is most influenced
- The cone resistance depends on the sequence and properties of all soils within the zone of influence.
- The cone resistance is influenced by the material ahead and behind the penetrating cone. Hence the cone will start to sense a change in material type before it reaches the new material and will continue to sense a material even when it has entered a new material. Therefore, the CPT/CPTu will not always identify the correct transition in thinly interbedded materials.

- The dimensions of this zone of influence depend on:
  - the cone size
  - the strength and stiffness characteristics of the soil.

2. CHALLENGING ISSUES OF CPTU INTERPRETATION



Sensing and development distance (after Tehrani et al. 2017)

Around a soil layer interface there is a zone where the measured resistance will be influenced by both the under- and overlying layer (the transition zone).
At a certain distance from the interface the underlying layer will be felt (sensing distance) and
a certain penetration in the underlying layer is needed to get rid of the effect of the overlying layer (development distance)

A thin layer is defined as a layer which has not sufficient height to develop the "true" resistance.

Transition zone: intervals when the peak of measured qt<<true resistance

2. CHALLENGING ISSUES OF CPTU INTERPRETATION

- The distance over which the cone senses an interface increases with material stiffness.

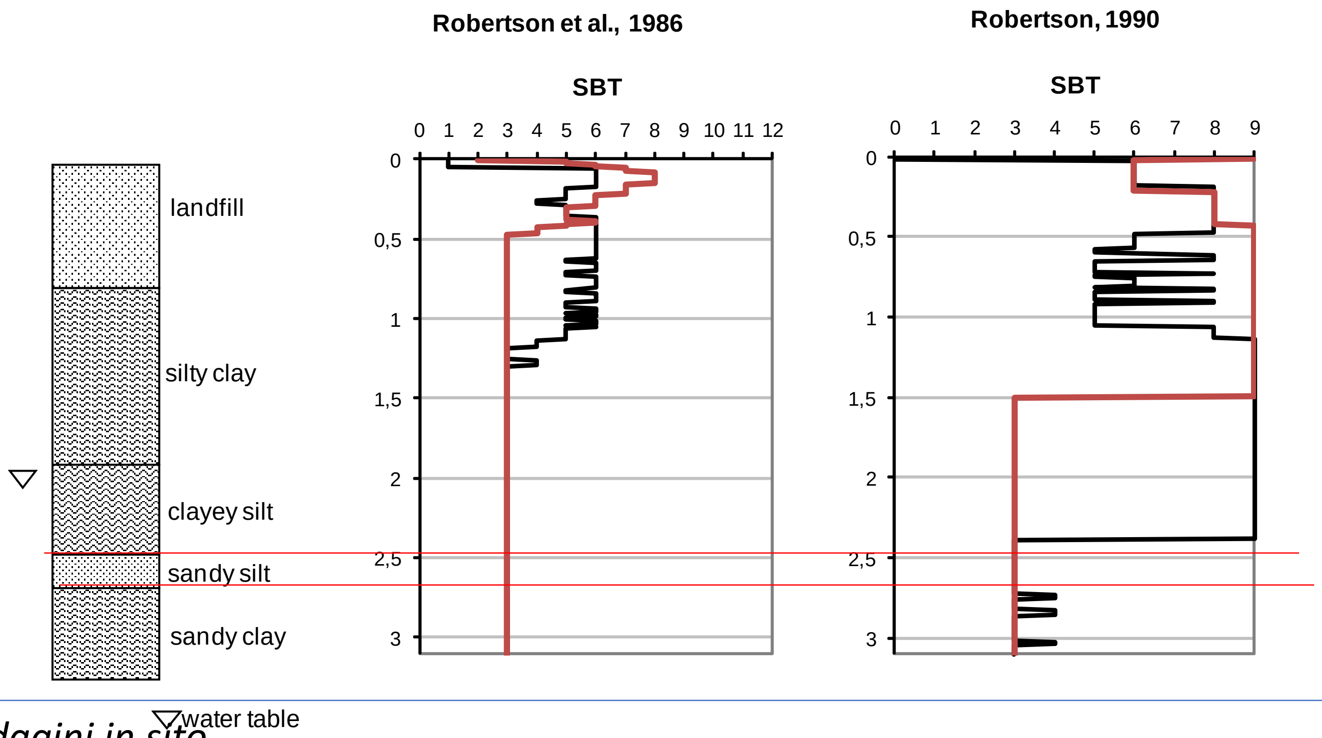
  - soft materials → diameter of the sphere of influence → <2-3 cone diameters → Soft layers thinner than 100 mm can be fully detected by the cone resistance

  - stiff materials → diameter of sphere of influence → up to l0 or 20 cone diameters → stiff layers may need to be as thick as 750 mm or more for the cone resistance to reach its full value.

2. CHALLENGING ISSUES OF CPTU INTERPRETATION

1. the minimum layer thickness that can be detected by penetration resistance (Vreugdenhil et al. (1994), Ahmadi and Robertson (2005))

- The detected thickness depends on the relative stiffness of two contiguous layers
  - the penetration resistance of a soft layer (clay) below a rigid layer (dense sand) is fully mobilized even for thicknesses of 1-2 diameters,
  - a thickness of 10-20 diameters is needed to fully mobilize the resistance of a rigid layer underneath a soft one.



2. CHALLENGING ISSUES OF CPTU INTERPRETATION

- thin layer effects can be important for liquefaction methodologies, depending on the analysis procedures, soil conditions, and seismic loading (Boulanger et al. 2016).

- The use of simplified one-dimensional (1D) liquefaction vulnerability indices (LVIs) can overestimate the potential for liquefaction induced deformations if the predicted intervals of liquefaction triggering are primarily associated with numerous thin layers or transition zones.

- In other cases, the results of 1D-LVI's may be insensitive to thin layer and transition zones if those zones are a small portion of the predicted intervals of liquefaction triggering (Boulanger and De Jong, 2018).

2. CHALLENGING ISSUES OF CPTU INTERPRETATION

- THIN LAYERS

- Difficult to identify in CPT (but also in borehole)

0 – 17 cm sand with silt

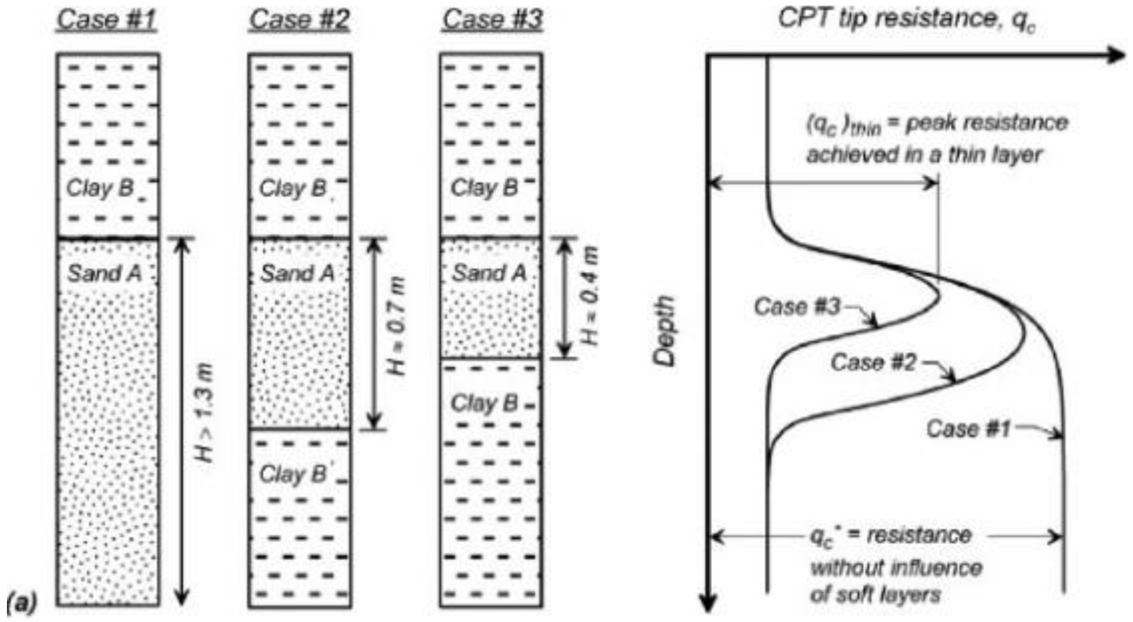
17 – 48 cm sandy clay silt;

48 – 85 cm sand with silt

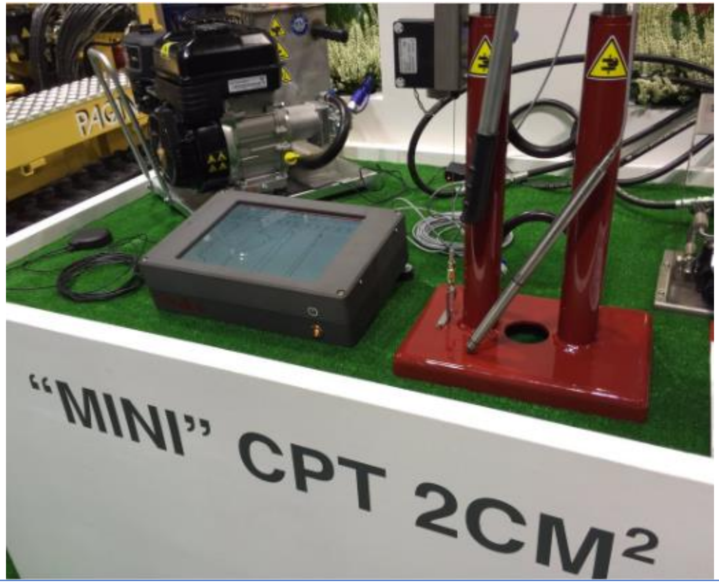
Gel push sample

3. POSSIBLE SOLUTIONS

- Thin layer correction (Boulanger and De Jong , 2018)



- Mini piezocone



3.1 Thin layer correction (Boulanger and De Jong, 2018)

The inverse filtering procedure has three primary components:

- (1) a model for how the cone penetrometer acts as a low-pass spatial filter in sampling the true distribution of soil properties versus depth,
- (2) a solution procedure for iteratively determining an estimate of the true cone penetration resistance profile from the measured profile and cone penetration filter model,
- (3) a procedure for identifying sharp transition interfaces and correcting the data at those interfaces.

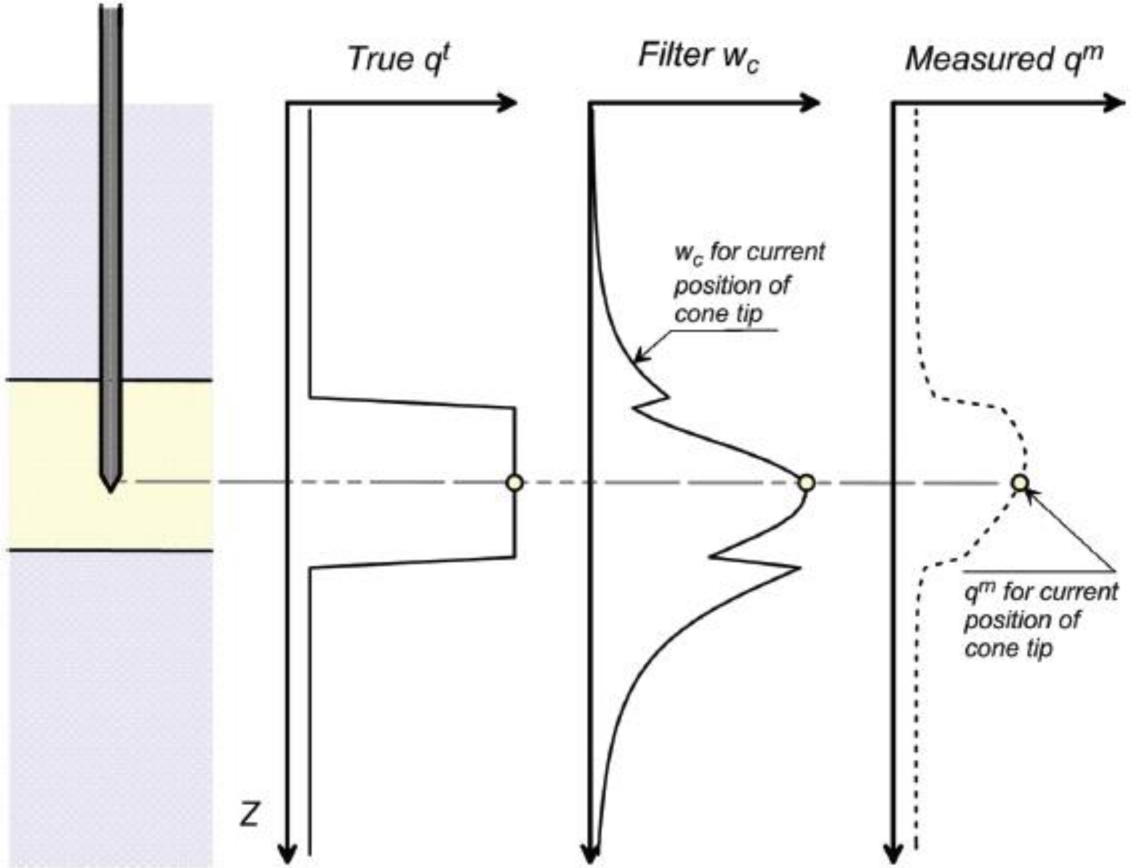


Figure 4. Illustration of the convolution of q^t with the cone penetration filter to obtain q^m at a given point in a layered profile.

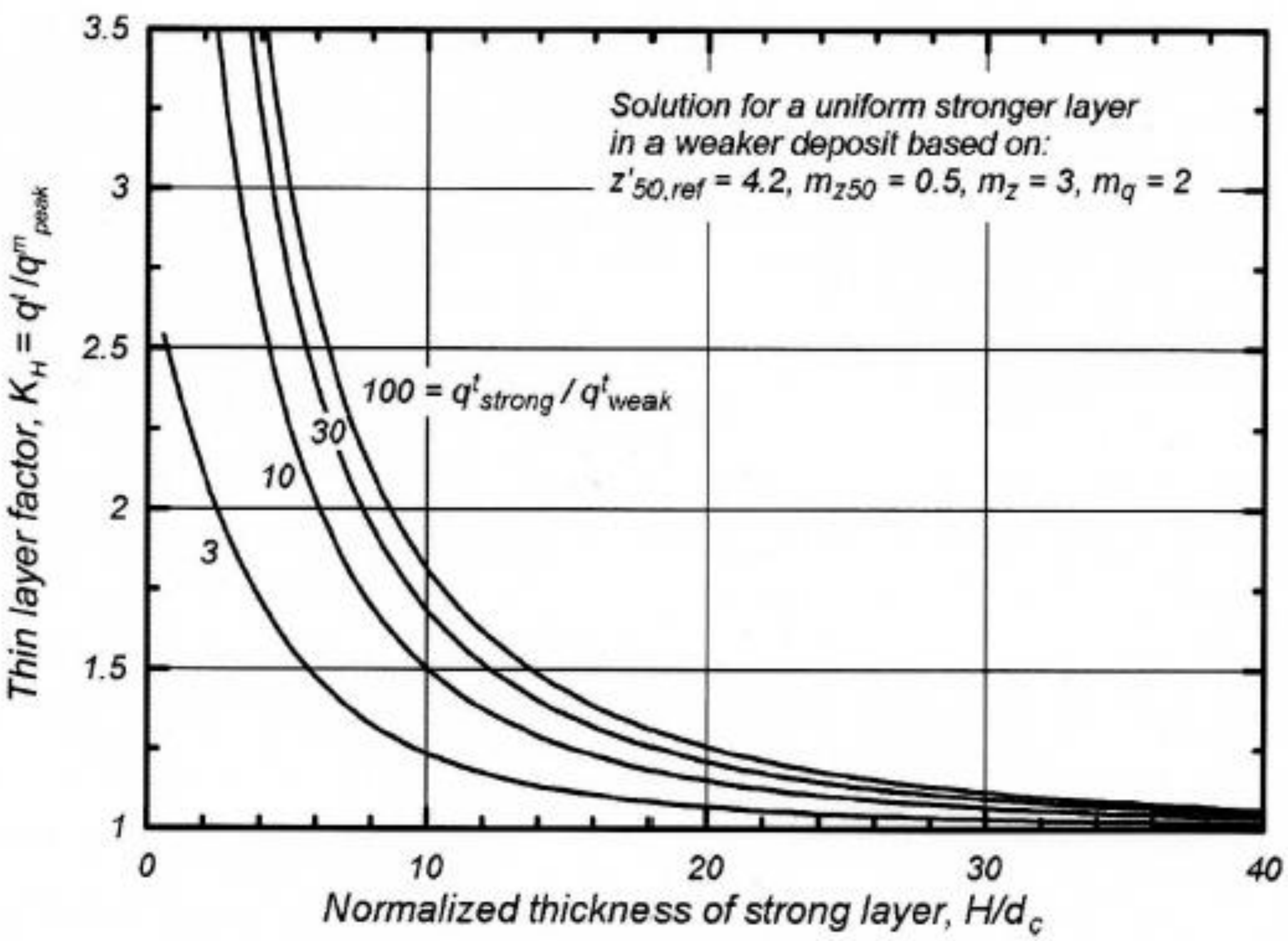
3.1 Thin layer correction (Boulanger and De Jong, 2018)

$$q_c^* = K_H \cdot q_{cA}$$

Where: q_c^* = correct tip resistance of layer A;

K_H = correction factor;

q_{cA} = measured tip resistance of layer A.



3.2 The minipiezocone

AUTHORS	TYPE OF MATERIAL	APPLICATION	AIM	NOTES
Tumay et al. (1998, 2001)		Transportation Geotechnics		mini cone with an apex angle of 60°, projected cone area of 2 cm^2 and a friction sleeve area of 40 cm^2 1 g conditions
Power & Geise (1995) and Tufenkjian & Thompson (2005)		seafloor exploration		1 g conditions
Lo Presti et al. (2018)	compacted, fine grained, partially saturated samples	Calibration Chambers	tests on fine – grained soils were used for predicting the degree of compaction	mini cone with a projected cone area of 0.5 cm^2 1 g conditions
Canou (1989)	fine silica sand samples (Hostun sand)	Calibration Chambers		mini cone with a projected cone area of 1 cm^2. 1 g conditions
Kurup et al. (1994) and Abu-Farsakh et al. (1998)	fully saturated cohesive soils	Calibration Chambers	pore pressure generation and dissipation	1 g conditions
Bolton *et al.* 1999		centrifuge testing		1 g conditions
De Lange (2018)	Laminated soil deposits		interpretation of CPT in thin layers	Mini cone with a diameter of 25 mm (5 cm2)

3.2 The minipiezocone

Comparaison between the results inferred from mini cones with those obtained with a standard cones in different soils

- the tip resistance from mini cone is higher (11%) than that of standard cone in the case of penetration tests on Tiller quick clay (Norway) (Tumay et al. 1998)
- Tufenkjian and Thompson (2005) found the opposite in the case of testing a laboratory reconstituted sand bed.
- Monfared and Sadrekarimi (2015) and Lo Presti et al. (2018) did not found any clear difference between standard and mini – cone tip resistances.
- These different results may depend on scale – effects i.e. different ratio between cone diameter dc and the mean grain size d50.
- Nikudel et al. (2012) tried to correlate the tip resistance measured in the first two meters with stiffness and strength parameters as inferred from laboratory tests in case of sandy soils.

4. AIMS OF THE RESEARCH

- to compare couples of standard and mini-piezocone tests carried out in **natural soil deposits** consisting of silty-sandy mixtures;

- To compare the thin layer correction (method of Boulanger and De Jong, 2018) results with mini CPTu;

- To investigate the capabilities and limitations of the mini-piezocone for a better identification of thin soil layers and improvement of liquefaction analysis in layered and multi-layered soil deposits.

5. METHODS

SITE TEST SELECTION

A. Silty clay (unsaturated conditions)

B. Silty sand (saturated consitions)

BOREHOLES

- Stratigraphy
- Grain size analysis
- Atterberg limits

PAIRS OF STANDARD CPTU AND MINI-CPTU

- Standard SBT and Ic profile
- Thin layer correction (Boulanger and De Jong, 2018) → Corrected SBT and Ic profile
- Mini SBT and Ic profile

Qc_{CPTu} VS $Qc_{mini\text{-}CPTu}$ VS $qc_{Corrected\ CPTu}$

Fs_{CPTu} VS $Fs_{mini\text{-}CPTu}$ VS $Fs_{Corrected\ CPTu}$

Ic_{CPTu} VS $Ic_{mini\text{-}CPTu}$ VS $IC_{Corrected\ CPTu}$

LPI (Liquefaction Potential Index) Boulanger and Idriss, 2016

5. METHODS

- mini-cone tip area (base area) was 2 cm^2, (16 mm in diameter)
- the friction sleeve area was 50 cm^2
- the cone apex angle was 60 degrees.
- The net area ratio of the miniature cone was 0,8.

Table 1 Full scale output of sensors

Measurement channel	Full scale output	Precision
Tip resistance (qc):	30 Mpa	0.005 MPa
Sleeve friction (fs)	0.5 MPa	0.04 kpa
Pore Pressure (U2)	2.5 MPa	0.04 kPa
Tilt	Not available	

5. METHODS

- The mini-cone is pushed into the soil at a relatively constant rate of 2 cm/sec.
- Lower force is required to push the mini-penetrometer into the soil (Tumay et al., 1998) and a smaller and lighter vehicle is necessary compared to the standard CPT test. This fact provides a greater mobility and site accessibility (Tufenkjian and Thompson, 2005).
- The maximum axial load experienced during the mini-cone tests was approximately equal to 0,9 kN.
- The mini-cone tip resistance and sleeve friction were recorded at depth intervals of 1 cm.

6. THE STUDY AREAS

- TEST SITE A.

Calendasco:

✓ silty clay soils

✓ thin layers: sand (thickness 13-35 cm) in silty clay

✓ Unsaturated conditions

✓ No liquefaction

- TEST SITE B.

Cavezzo:

✓ silty - sandy soils

✓ thin layers (silty layers in sandy soils and sandy layers in silty soils)

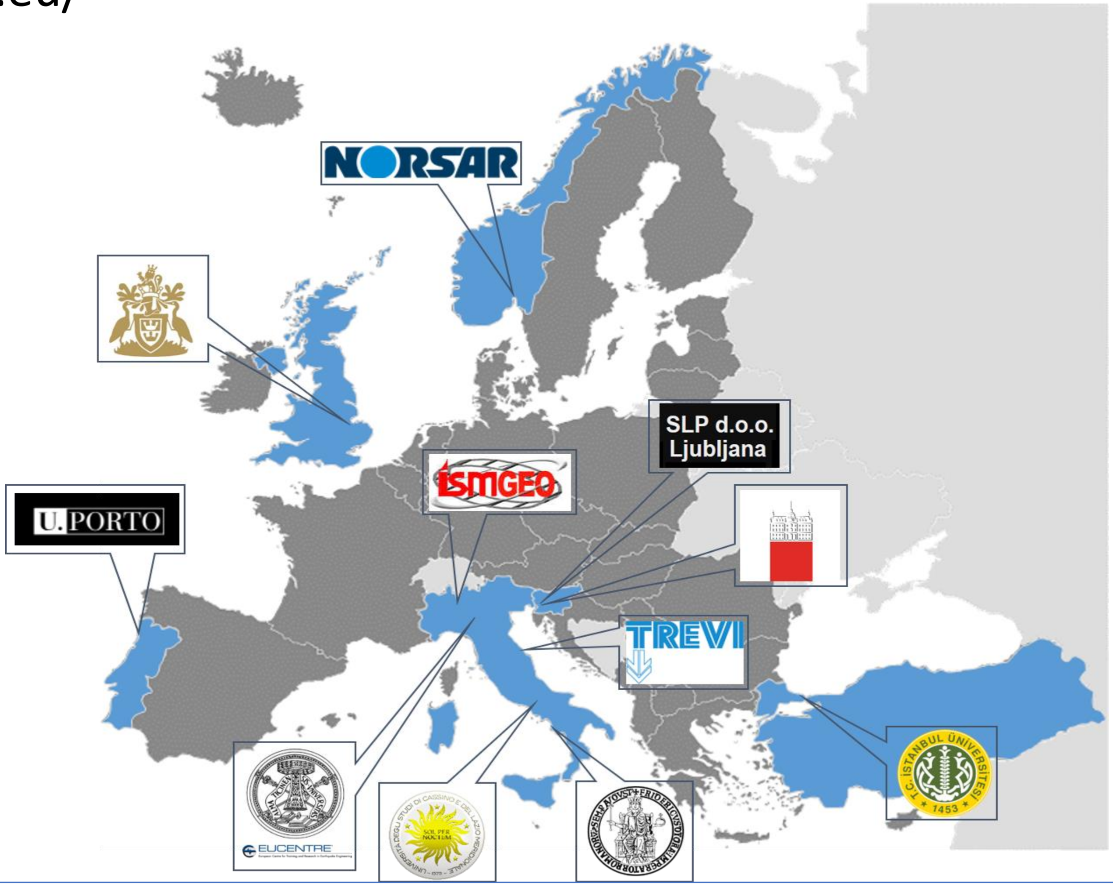
✓ Saturated conditions

✓ liquefaction

http://www.liquefact.eu/

ASSESSMENT AND MITIGATION OF LIQUEFACTION POTENTIAL ACROSS EUROPE

A holistic approach to protect structures / infrastructures for improved resilience to earthquake-induced liquefaction disasters

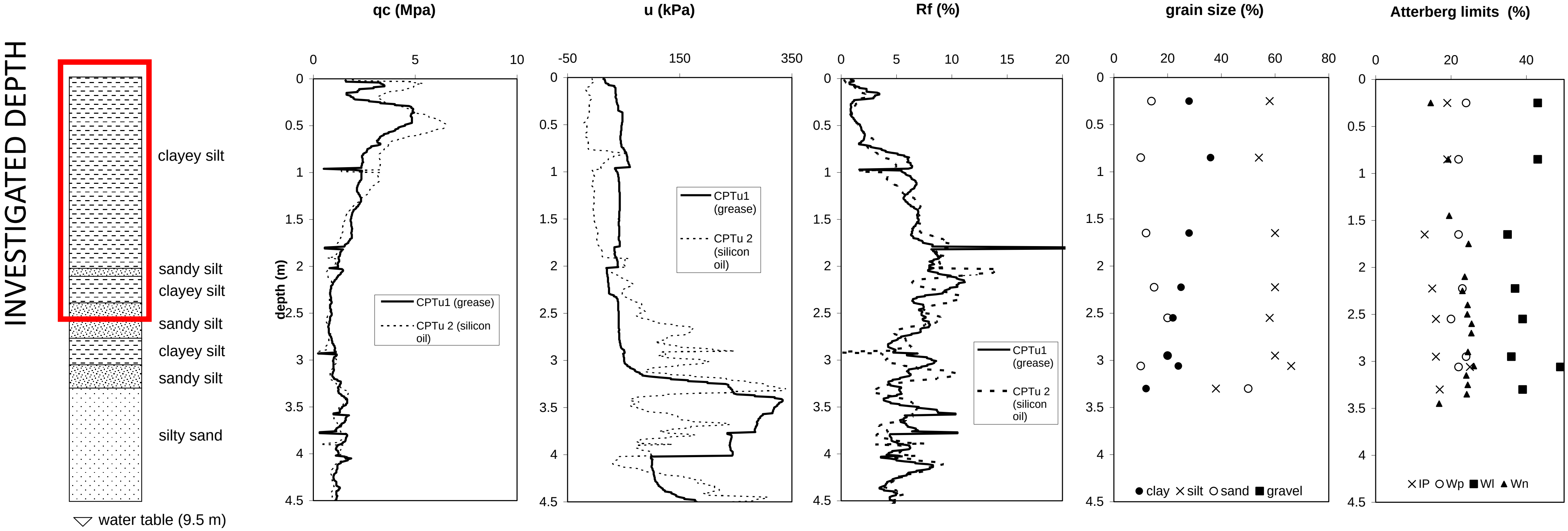


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement GA700748

6.1 TEST SITE A

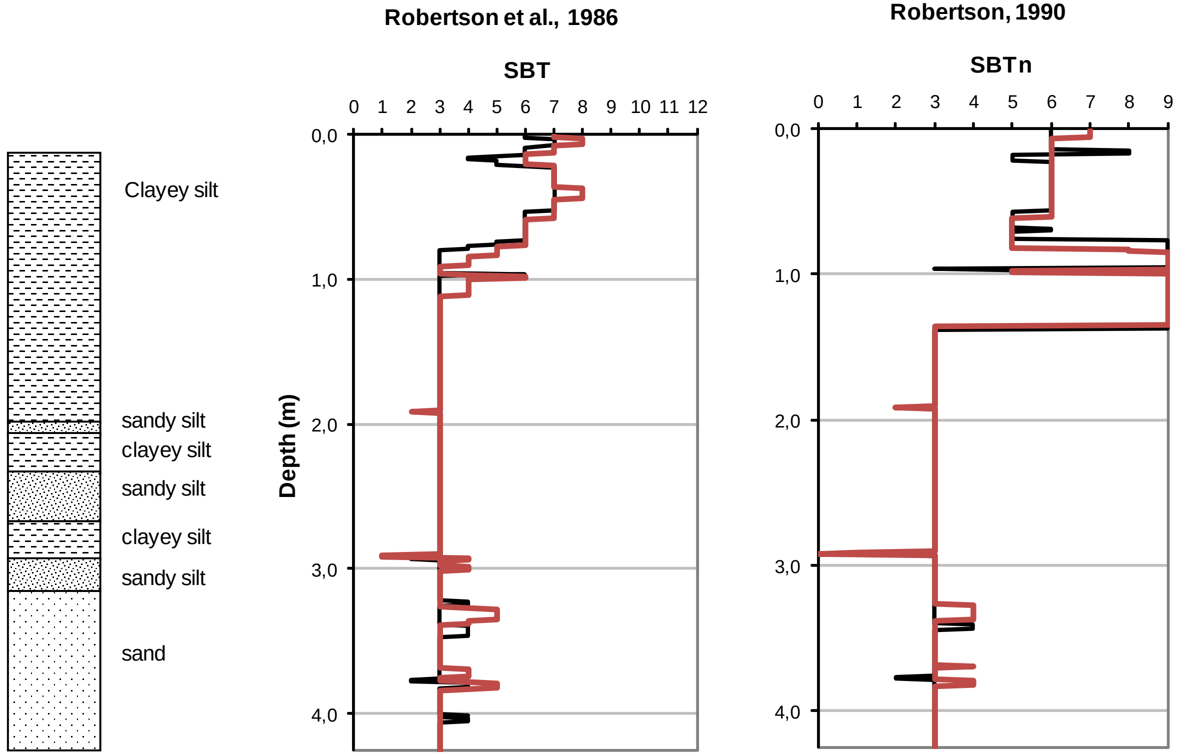
Olocenic deposits of the River Po in Calendasco (Piacenza, Northern Italy).

6.1 TEST SITE A



Olocenic deposits of the River Po in Calendasco (Piacenza, Northern Italy). Clayey silts and sandy silts (CL) with sandy intercalations down to a variable depth of between 8.6 and 6.6 m. At greater depths there is a gravelly layer. The water table is 9.5 meters below ground surface.

6.1 TEST SITE A



1- Sensitive fine-grained soil
2- Organic soil
3- Clay
4- Silty clay to clay
5- Clayey silt to silty clay
6- Sandy silt to clayey silt
7- Silty sand to sandy silt
8- Sand to silty sand
9- Sand
10- Sand to gravelly sand
11- Very stiff fine-grained soil
12- Overconsolidated or cemented sand to clayey sand

1- Sensitive fine-grained soil
2-Organic soils and peat
3-Clays (clay to silty clay)
4-Silt mixtures (silty clay to clayey silt)
5-Sand mixtures (sandy silt to sil.sand)
6-Sand (silty sand to clean sand)
7-Sand to gravelly sand
8-Sand - Clayey sand to very stiff sand
9-Very stiff, fine-grained, overconsolidated or cemented soil

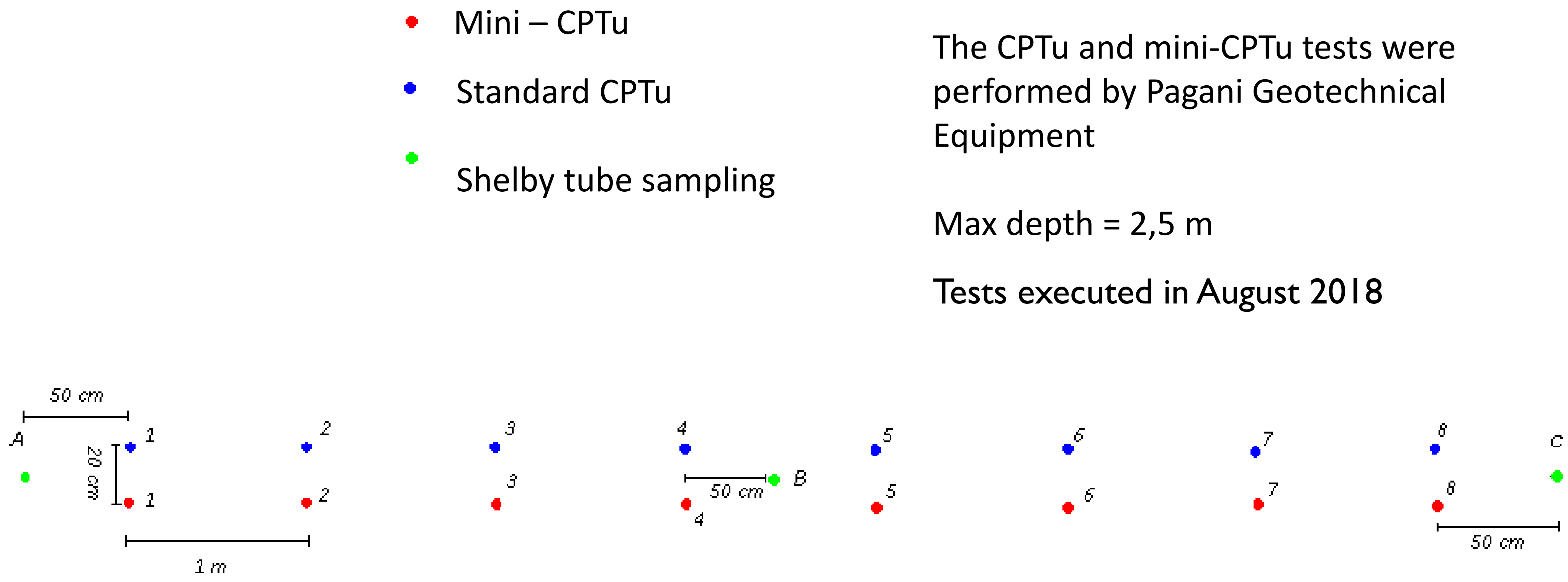
Calendasco. Comparison between stratigraphical profile of the borehole and those obtained through CPTu tests. SBT: soil behavior (in black: CPTU1, in red: CPTU2)

The clayey silts between 0.6 m and 1 m are distributed in numerous fields.

The superficial silty clay layer is identified as sandy silt/silty sand by Robertson et al. (1986) and as sand by Robertson (1990).

The variability in the interpretation of the layer from 0 cm to 2.10 m and the overestimation of soil grain size can be explained by the presence of a partially saturated layer, which leads to an increase of the resistances, particularly evident in the classification obtained with the Robertson method (1990).

6.1 TEST SITE A



The CPTu and mini-CPTu tests were performed by Pagani Geotechnical Equipment

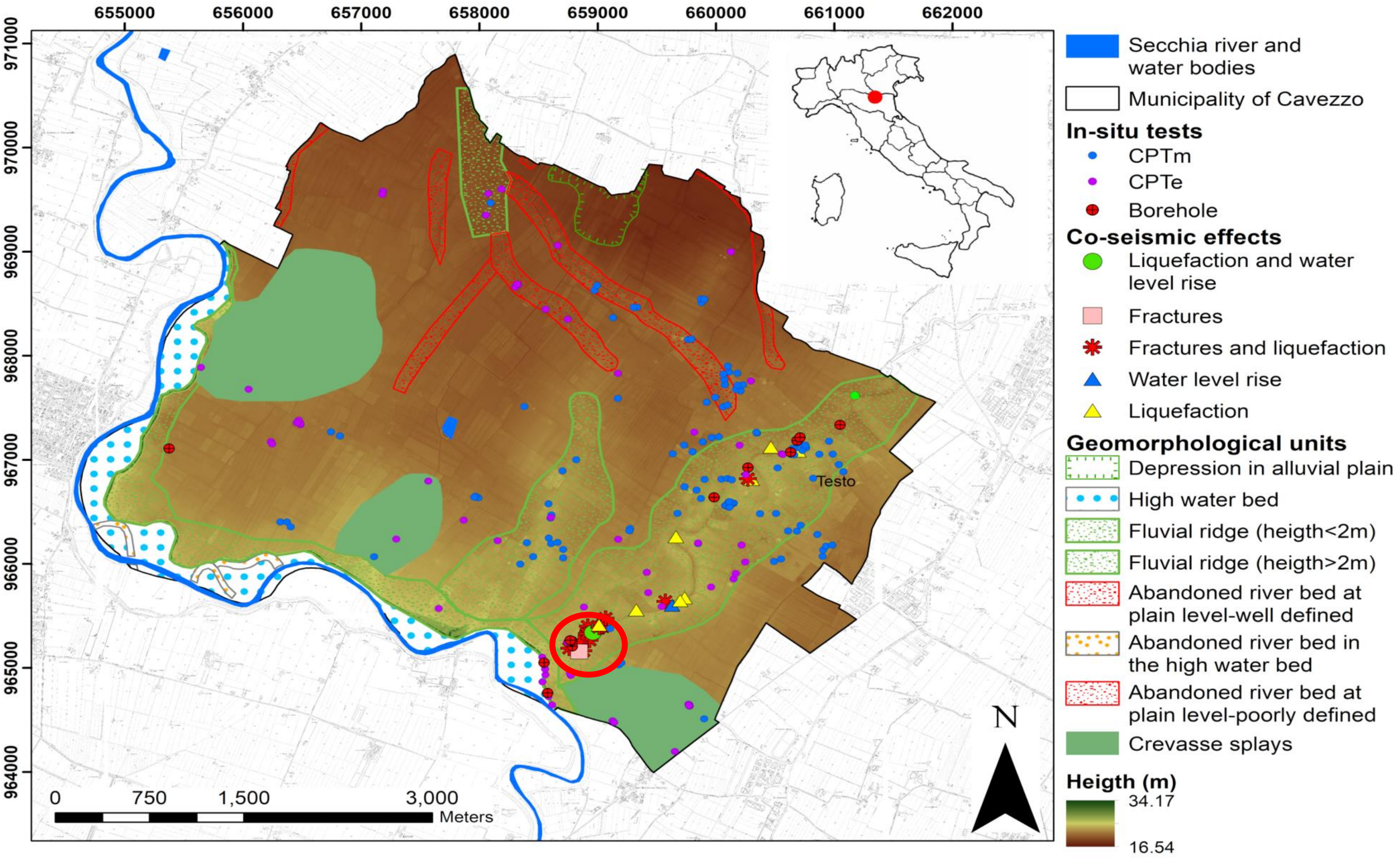
Max depth = 2,5 m

Tests executed in August 2018

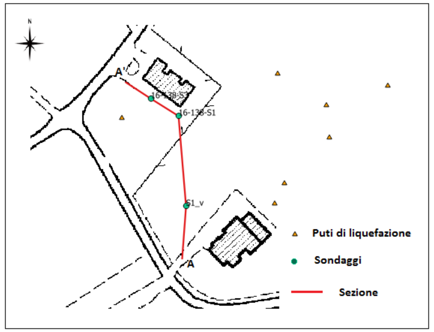
6.2 TEST SITE B

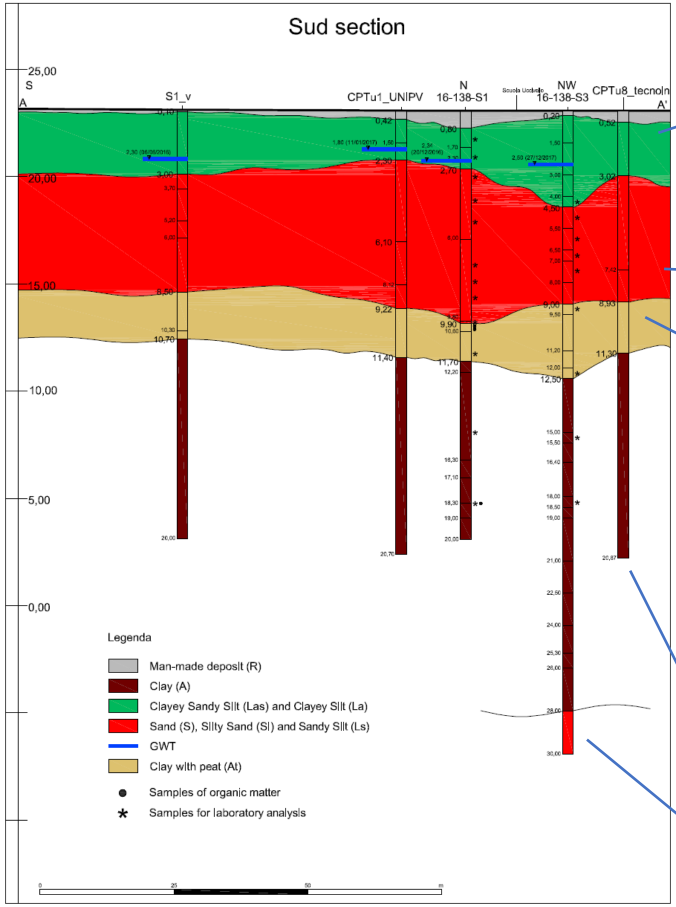
Water table depth from 1 m (S) to 4-5 m (N)

Study area



6.2 TEST SITE B





UNIT A: heterogeneous deposits, lithological classes clayey silt and clayey sandy silt (La, Las), with interbedded thin silty sand (Sl) layers (Recent alluvial plain)

UNIT B: lithological classes sand (S), silty sand (Sl) and sandy silt (Ls) (Fluvial channel).

Studied soils

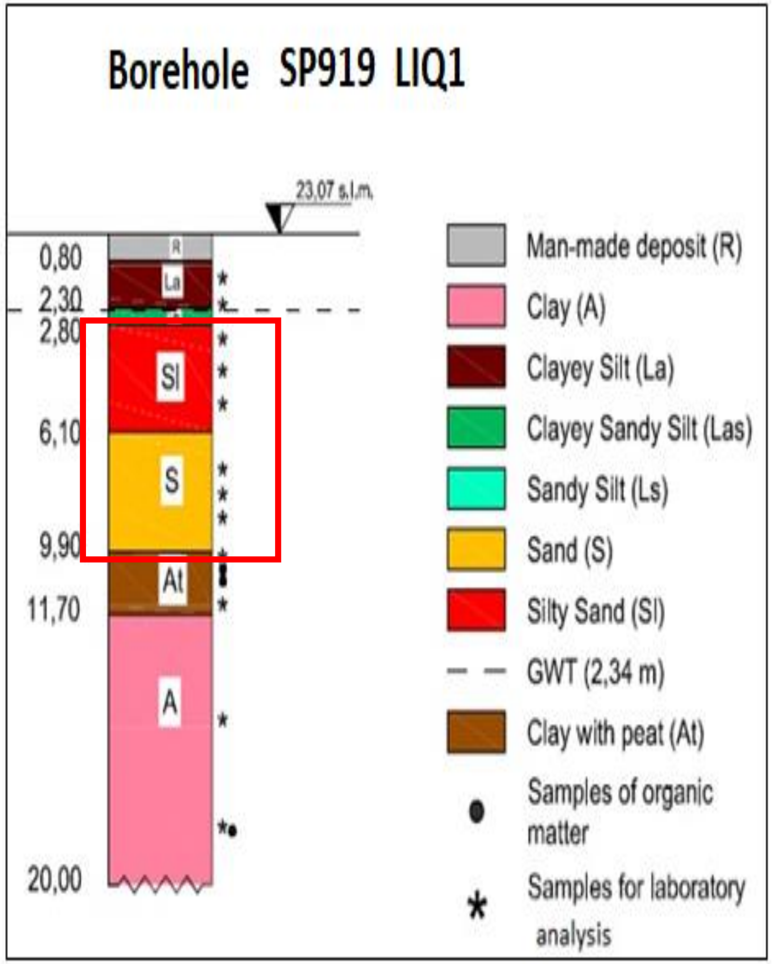
UNIT C: clay (A) and clay with peat (At), (lacustrine depositional environment).

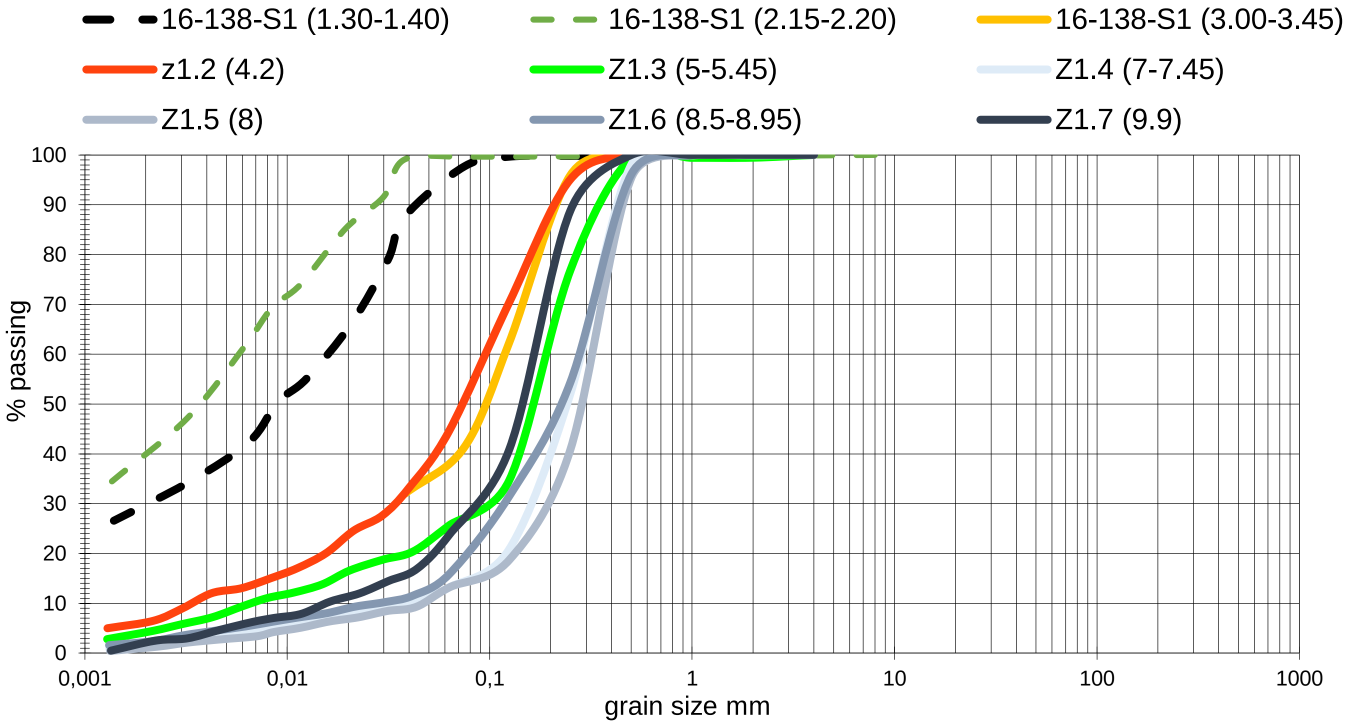
UNIT D: clay (A),(Ancient alluvial plain).

UNIT E: dense sands (Ancient fluvial channel) .

6.2 TEST SITE B

Layer (m)	USCS	FC (%)	Wl (%)	IP
La (0,8-3,2)	CL	90-98	38-41	19-23
Sl (3,2-4,6)	CL	35	25	8
Sl (4,6-6,0)	SM	20-38	-	-
S (6-9,9)	S	10-20	-	-
A (>9,9)	CH	94-99	58-66	41-45

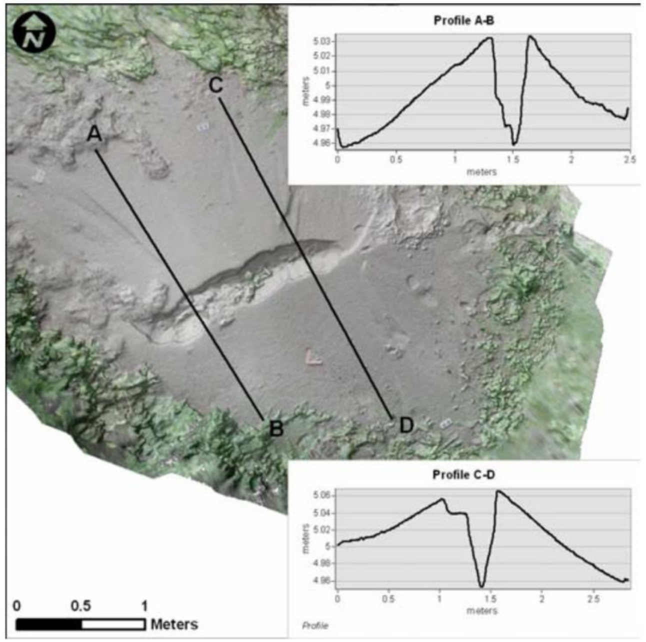


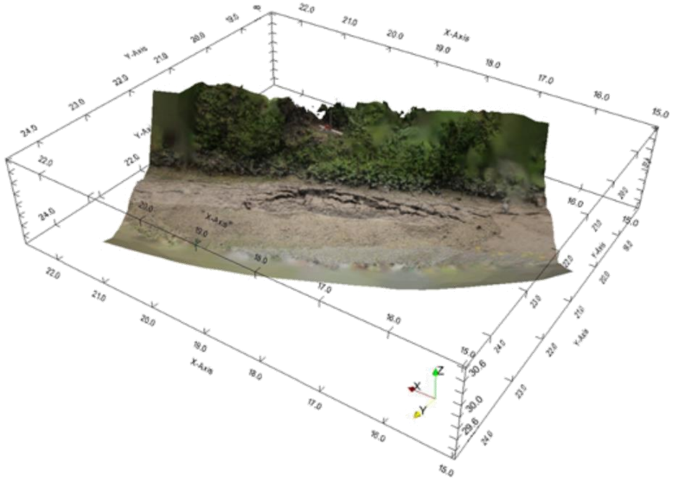


Liquifiable layers

6.2 TEST SITE B

Liquefaction phenomena

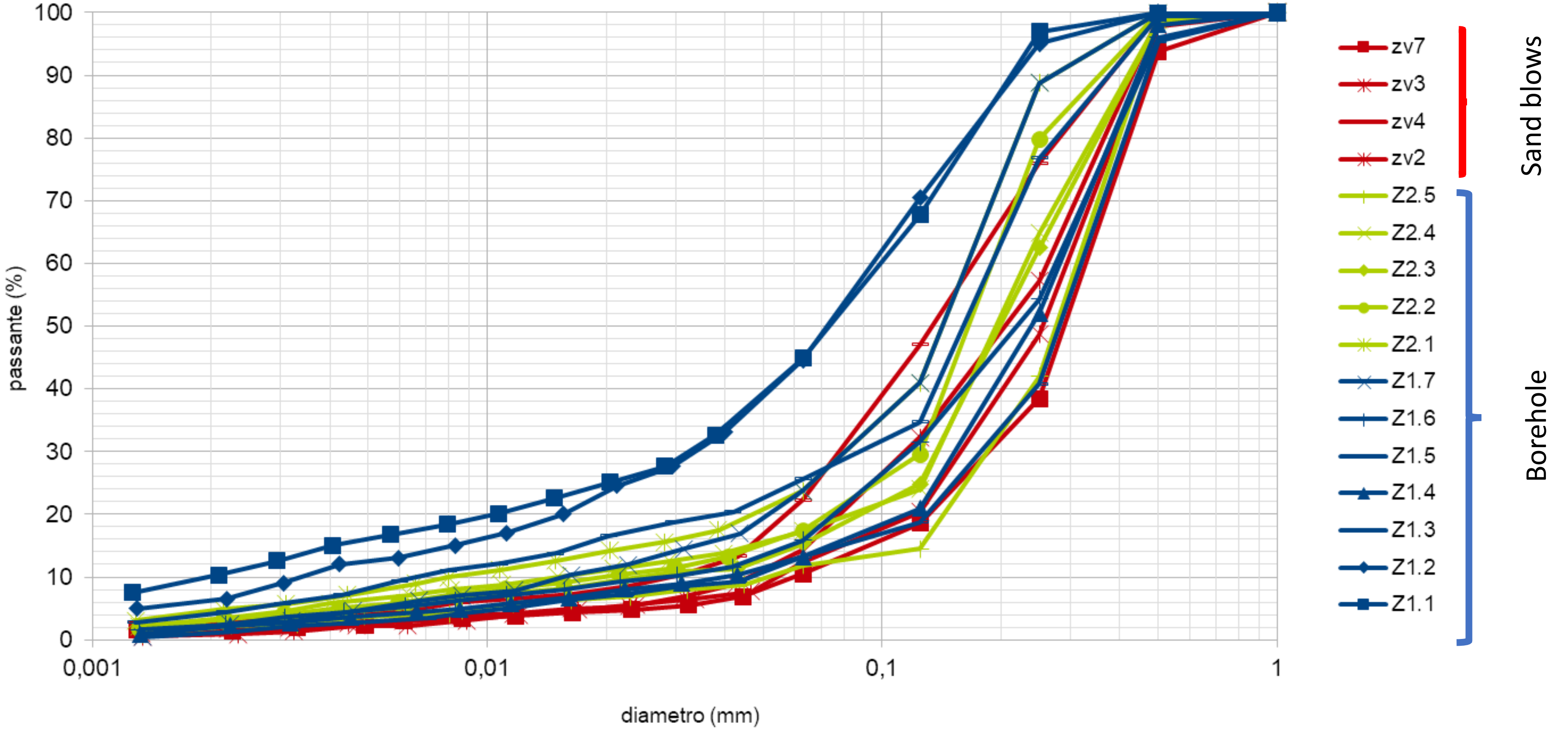




Phenomena
were triggered by the May 29th (M=5.8) earthquake.

6.2 TEST SITE B

Grain size analyses of sand from boreholes and sand blows.
Sands are well selected medium to fine-grained.
Sand blows are slightly more selected that the sand from the source layers as a result of the ejection mechanism

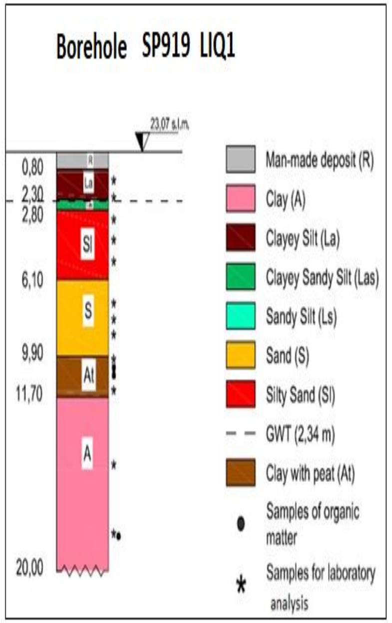


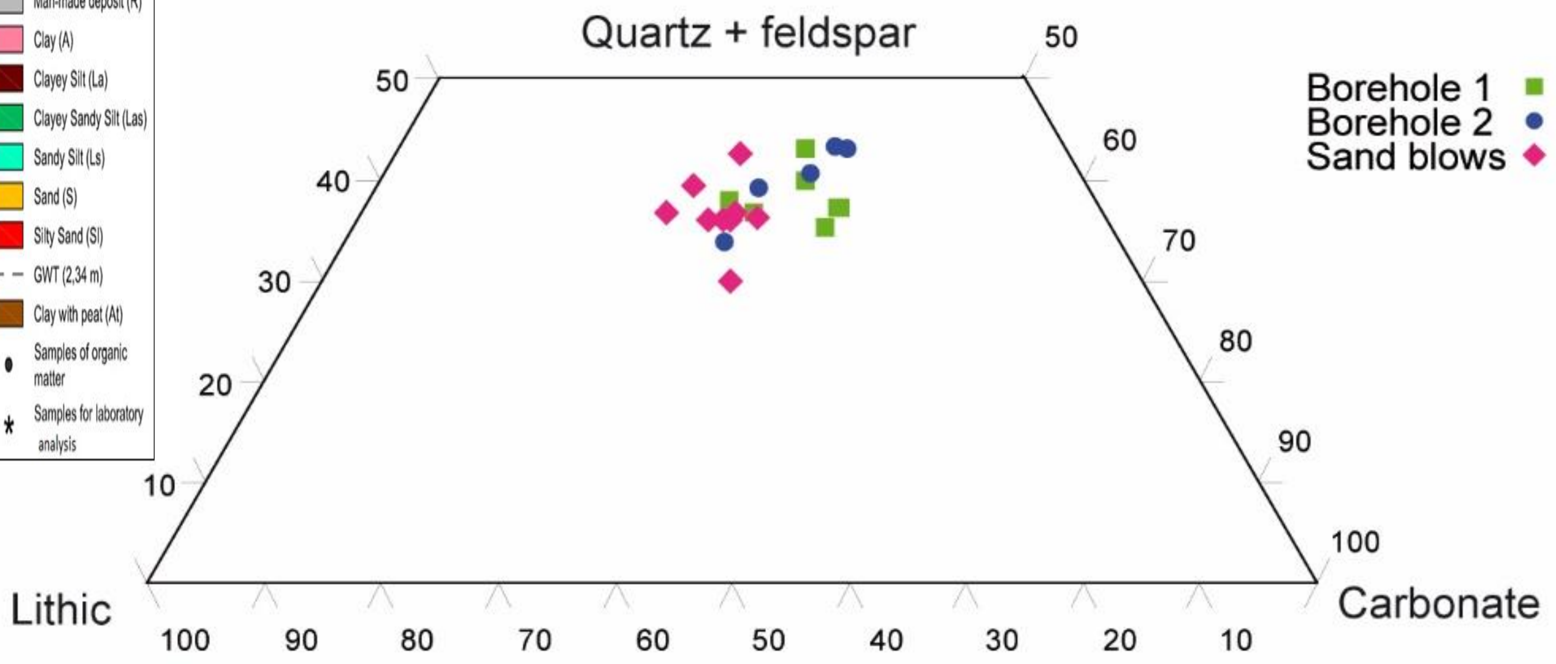
6.2 TEST SITE B

Composition of liquefied sands

Modal analyses of sand from two boreholes (1, 2) and sand blows

The composition of sand blows overlap the composition of shallow sand layers from both boreholes down to the depth of 4.5 m.





Collaboration with University of Modena Dipartimento di Scienze Chimiche e Geologiche

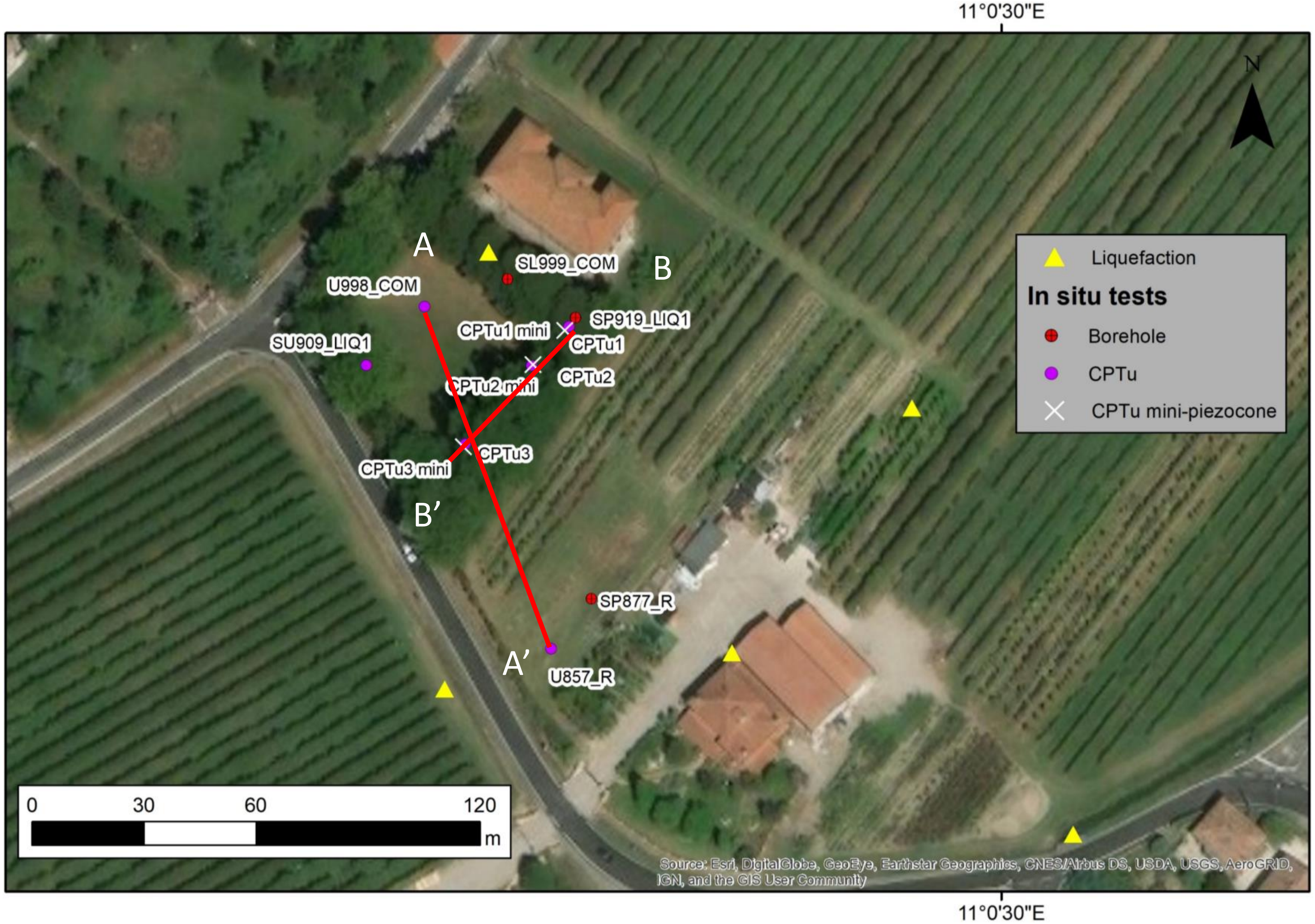
6.2 TEST SITE B

Test design

The CPTu 1, 2, 3 and mini-CPTu tests 1, 2, 3 were performed by Pagani Geotechnical Equipment
Depth mini-CPTu1: 10 m
Depth mini CPTu2: 10 m
Depth mini CPTu3: 5 m

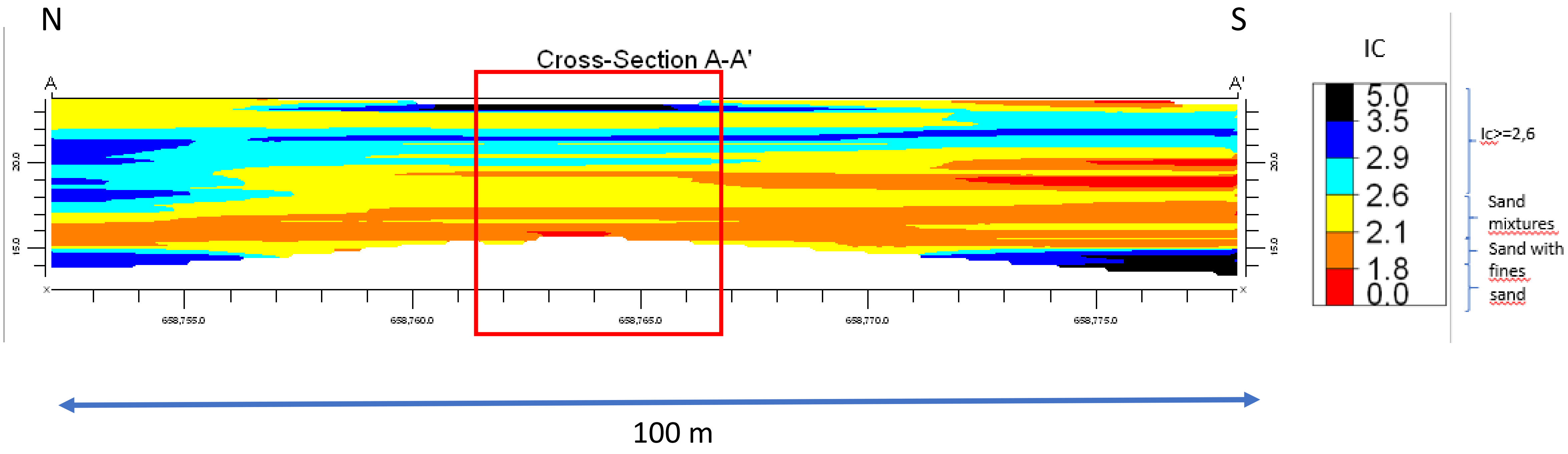
The CPTu U998_COM: database RER

the boreholes SP919_LIQ1, SL999_COM were performed in the frame of the project Horizon 2020 LIQUEFACT



6.2 TEST SITE B

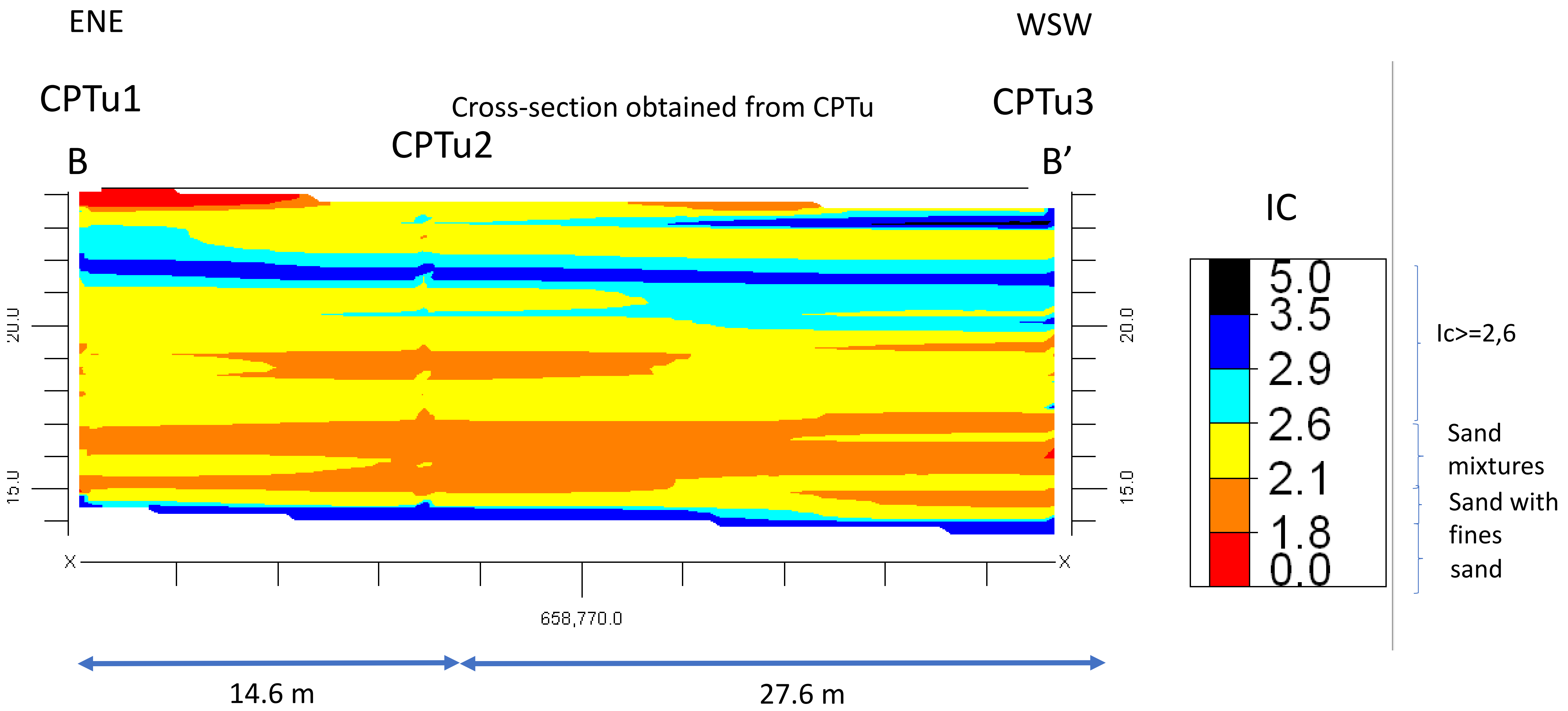
Cross-section obtained from CPTu



The CPTu and mini-CPTu tests location

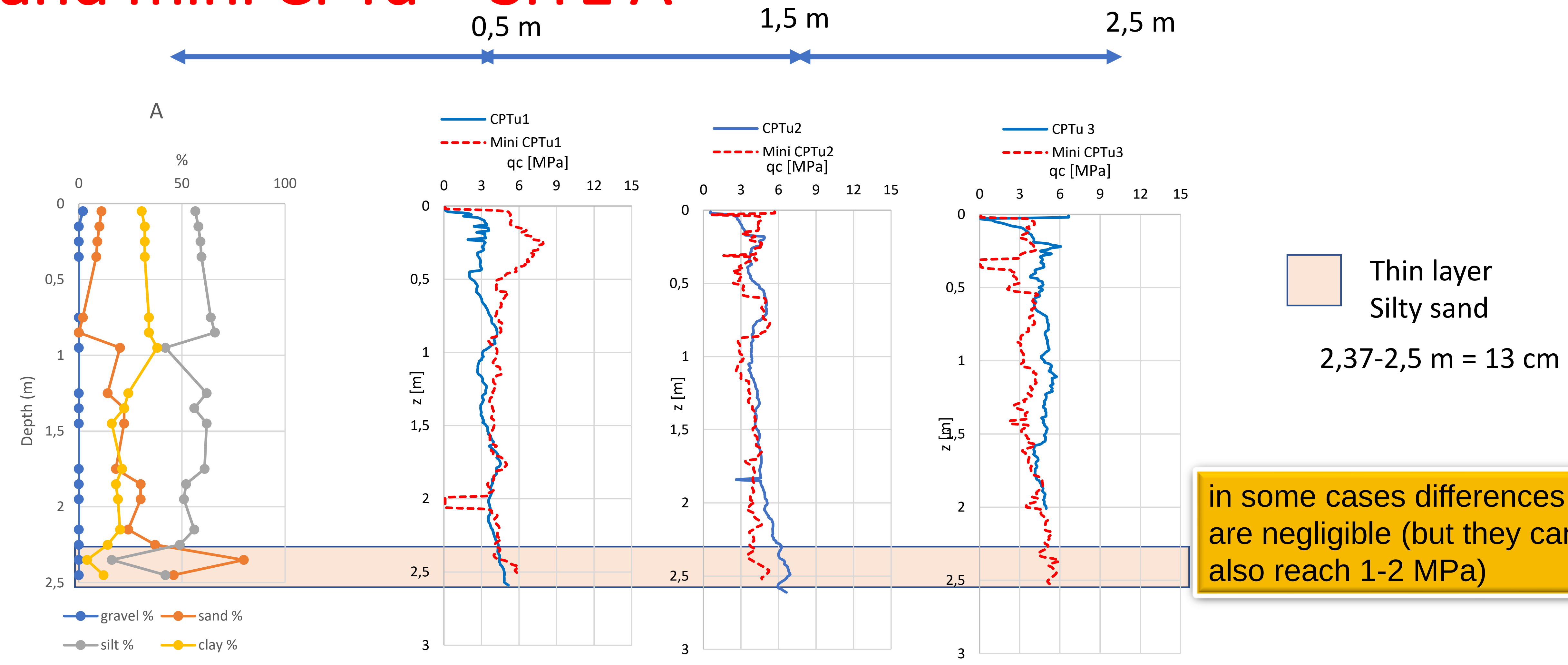
Vertically and horizontally heterogeneous deposits

Cross-section obtained from CPTu



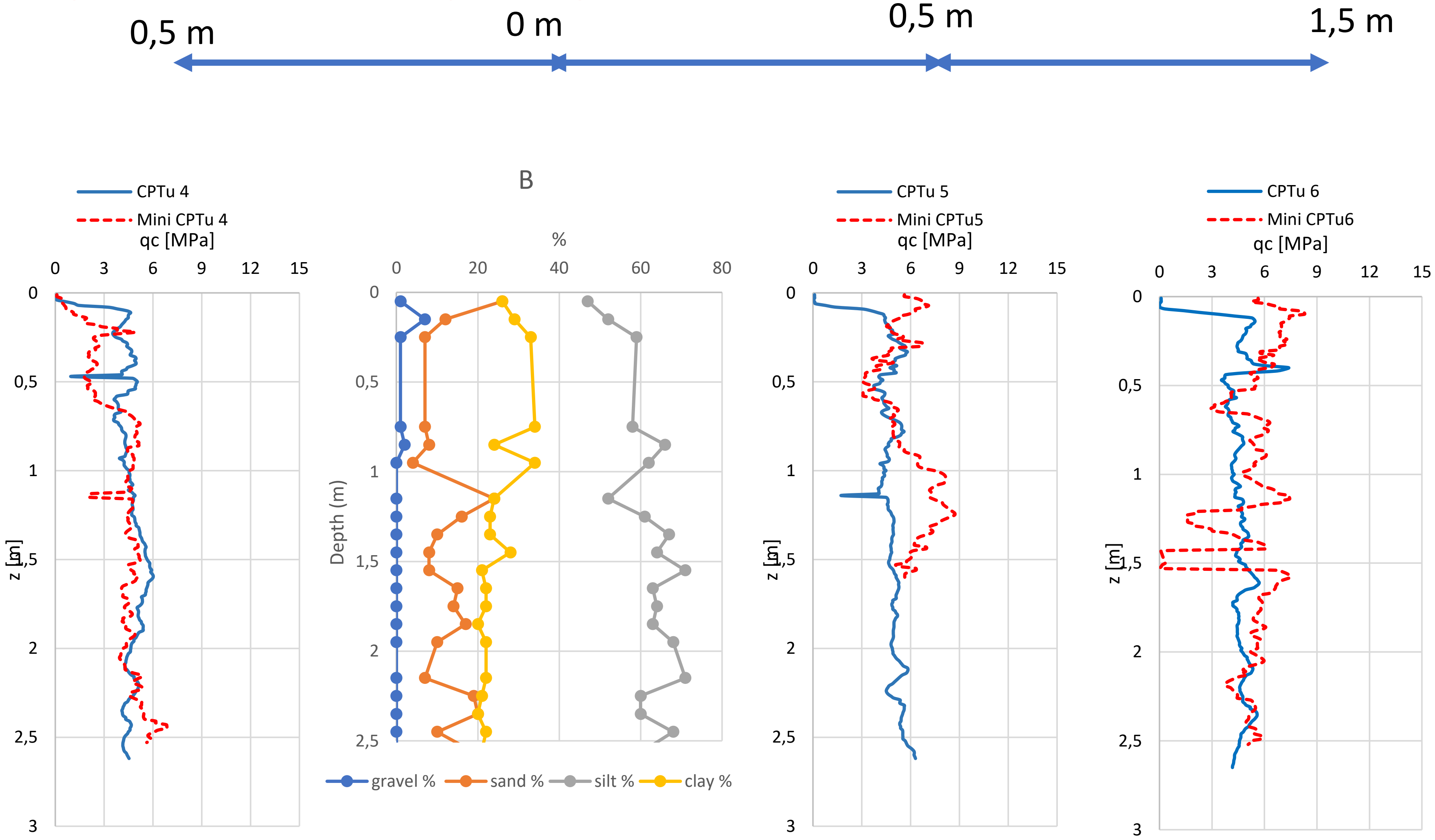
Distance CPTu and miniCPTu = 0,5-0,8 m

7. RESULTS - Comparison Qc standard CPTu and mini CPTu – SITE A



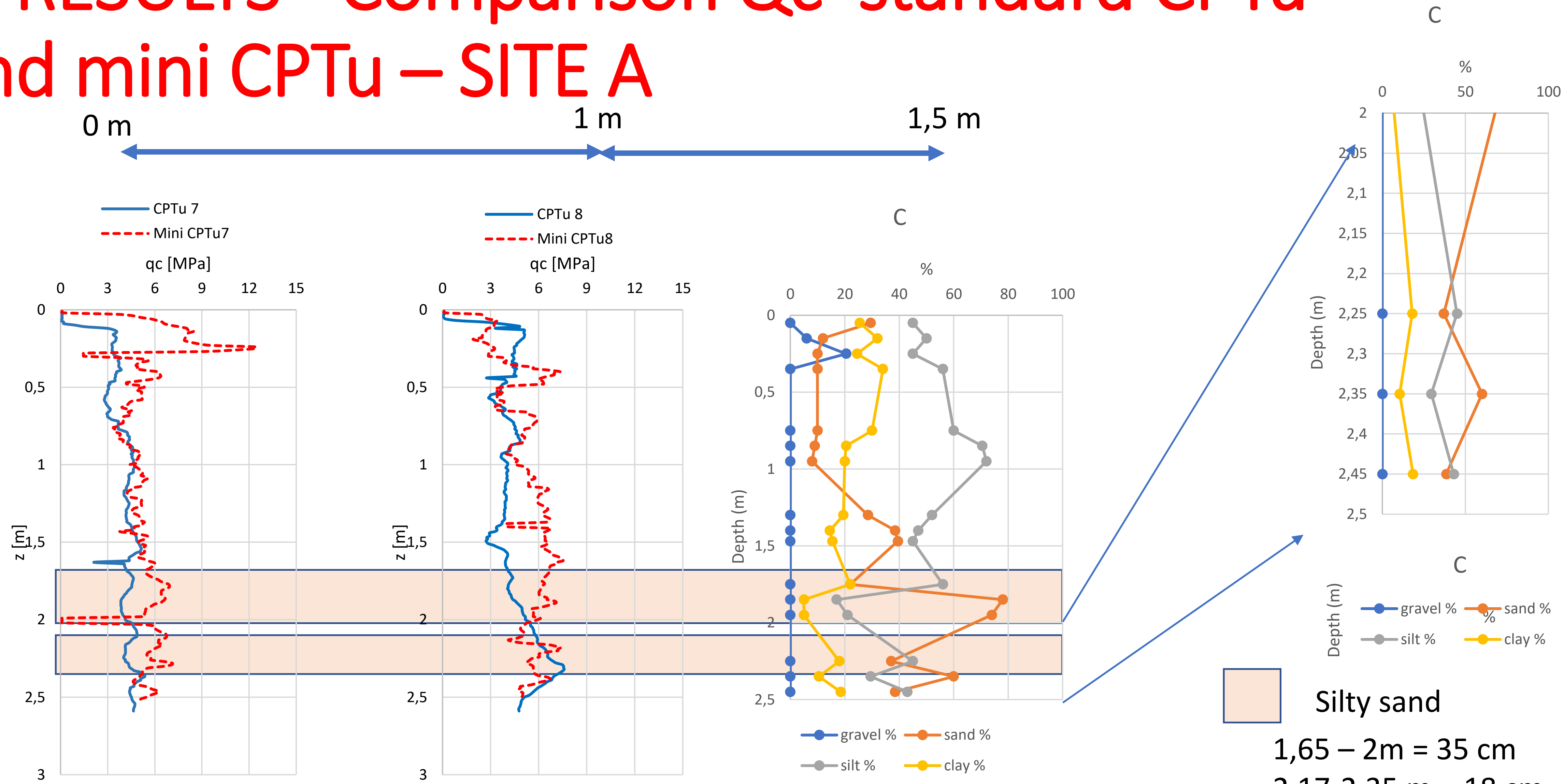
in some cases differences are negligible (but they can also reach 1-2 MPa)

7. RESULTS - Comparison Qc standard CPTu and mini CPTu – SITE A



differences are not related to differences in grain size

7. RESULTS - Comparison Qc standard CPTu and mini CPTu – SITE A



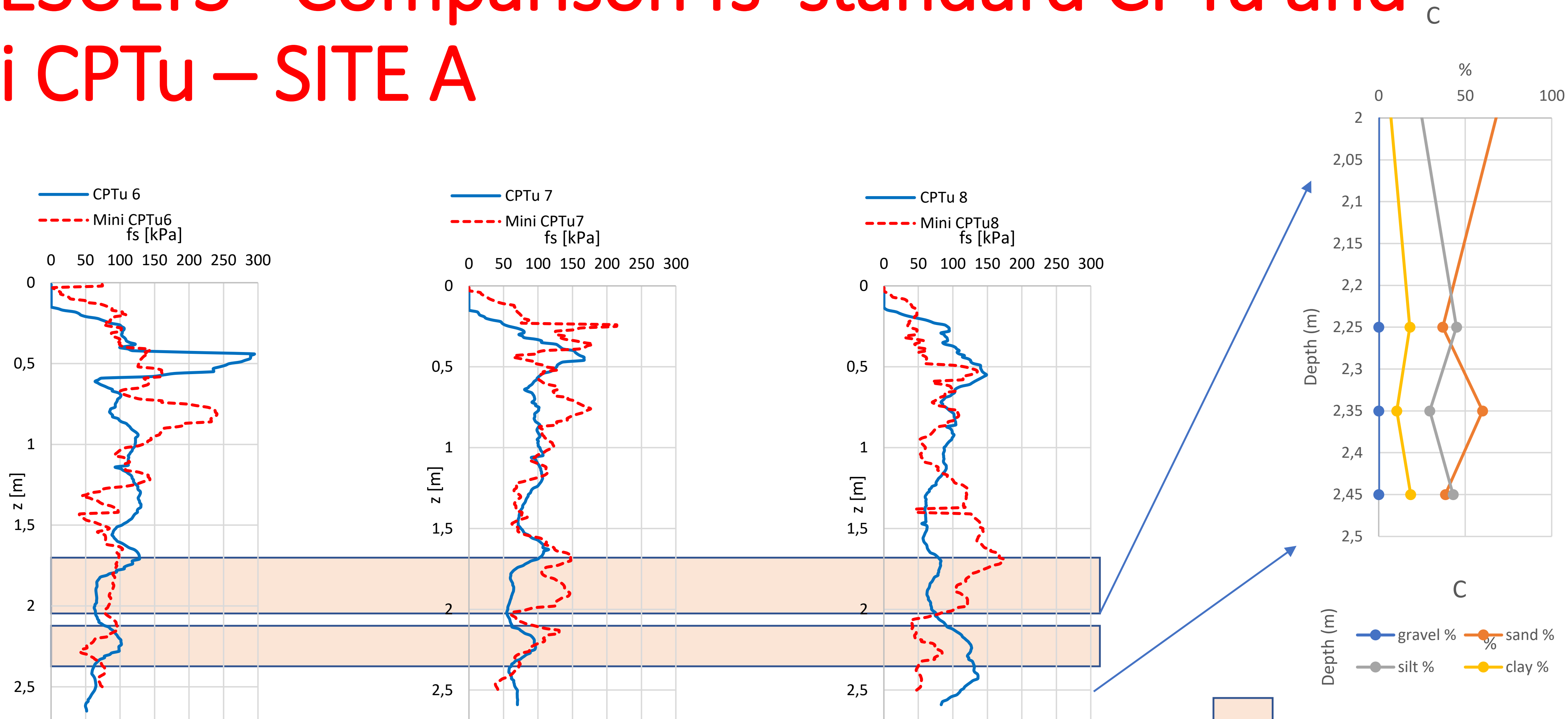
Silty sand

1,65 – 2m = 35 cm

2,17-2,35 m = 18 cm

differences are not systematic, generally qc standard < qc mini

7. RESULTS - Comparison fs standard CPTu and mini CPTu – SITE A



Silty sand

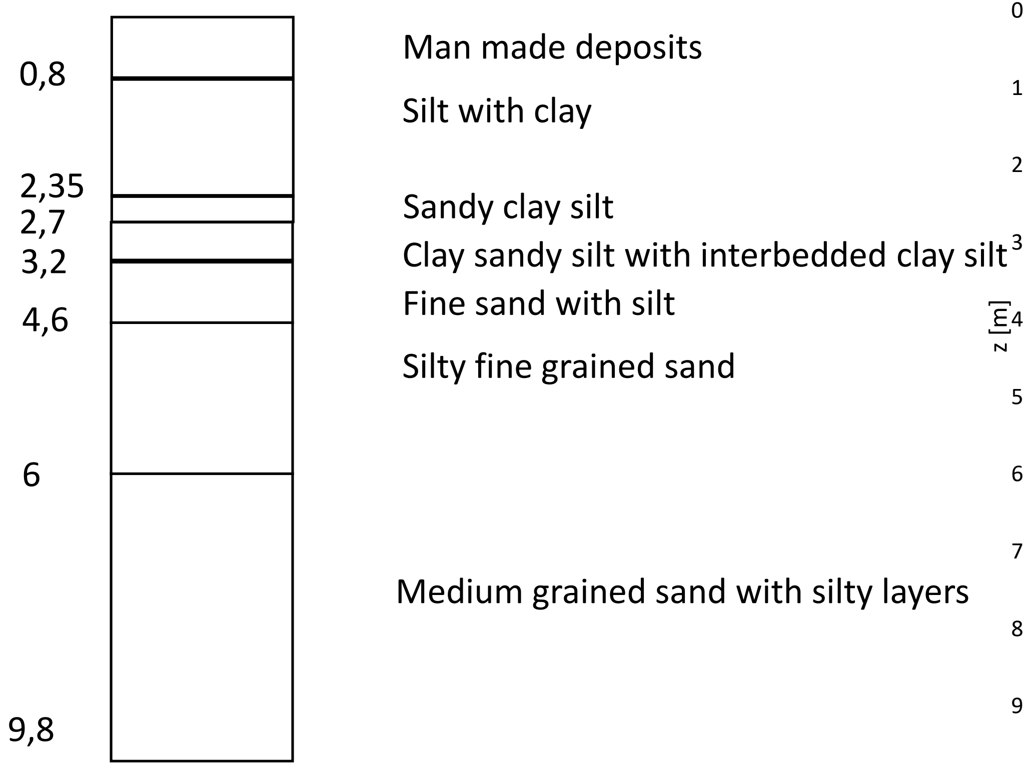
1,65 – 2m = 35 cm

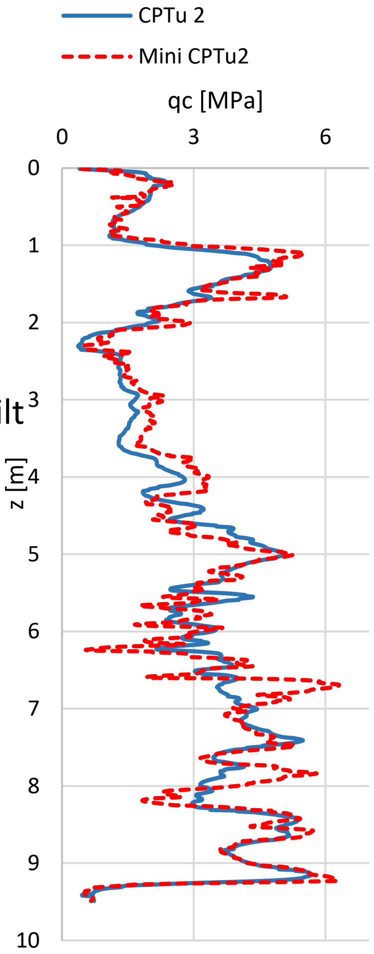
2,17-2,35 m = 18 cm

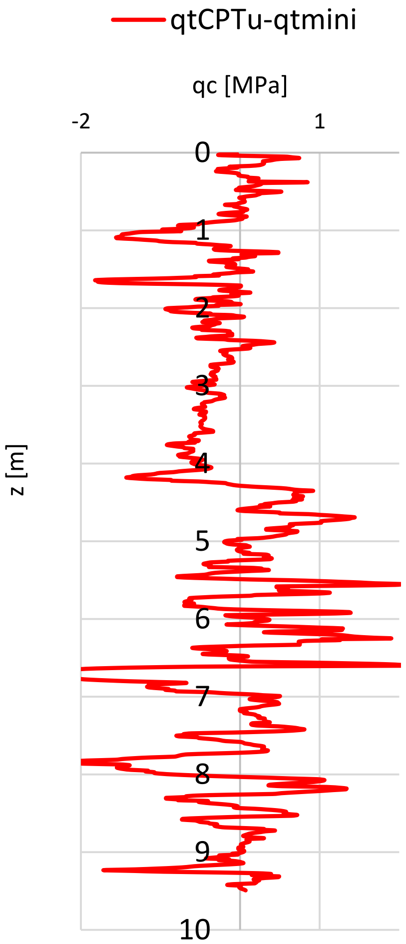
differences are not systematic

7. RESULTS - Comparison Qc standard CPTu and mini CPTu – SITE B

Distance CPTu2-miniCPTu2 = 0,5 m







0,8-3,2 m:
low differences

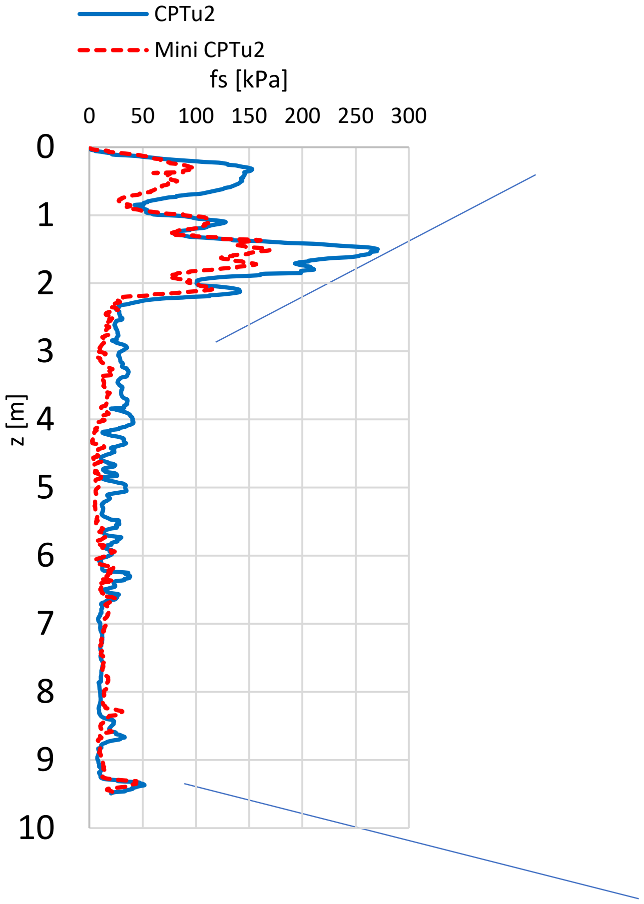
3,2-4,6 m:
low differences (Δ = 0,5-0,8 Mpa)
(qcstandard<qc mini)

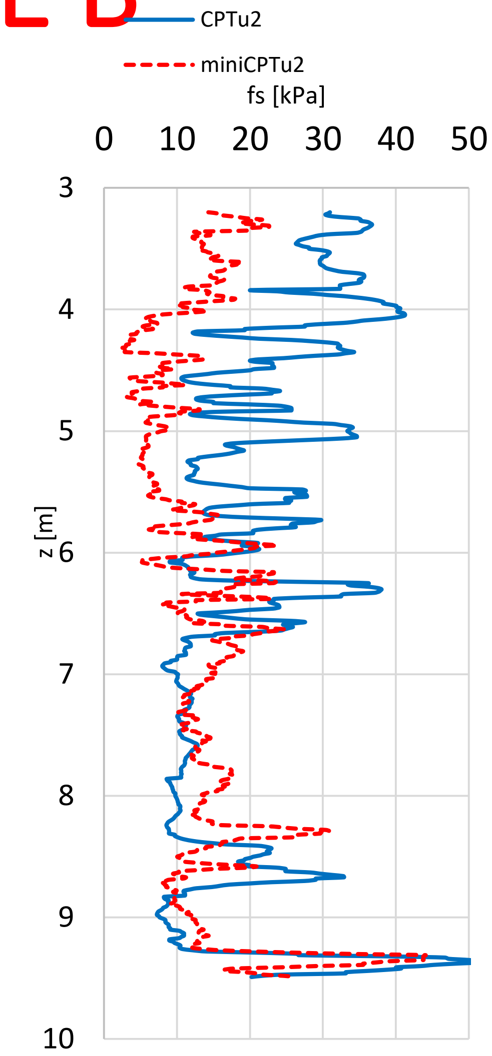
4,6-6 m:
Δ = 2MPa; (qcstandard>qc mini)

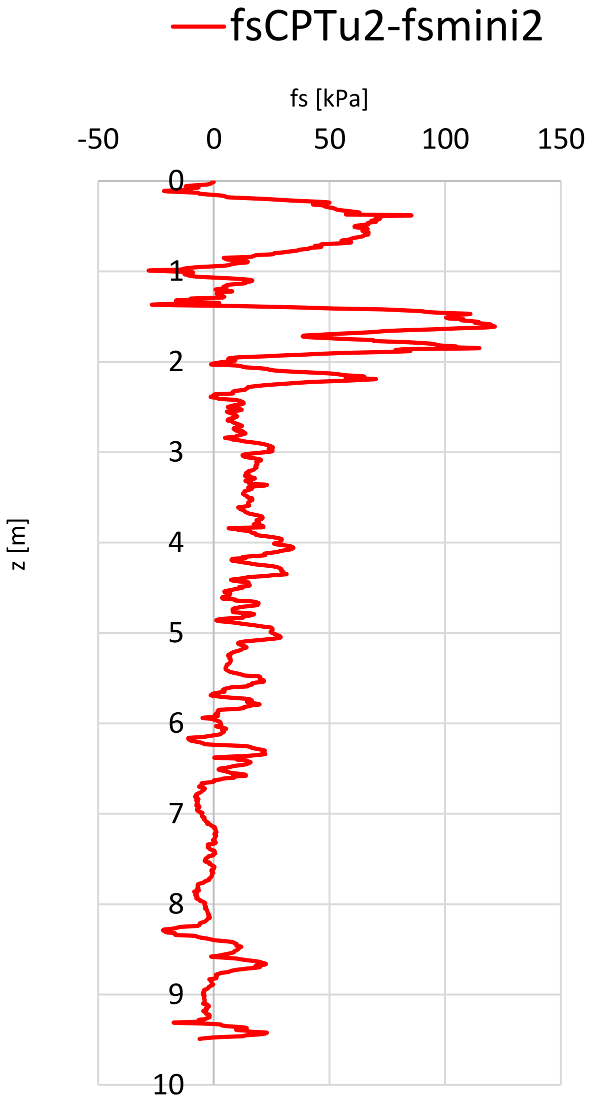
6-9,8 m:
Δ = 2MPa; (qcstandard<qc mini)

Differences are related to lithological variations?

7. RESULTS - Comparison fs standard CPTu and mini CPTu – SITE B



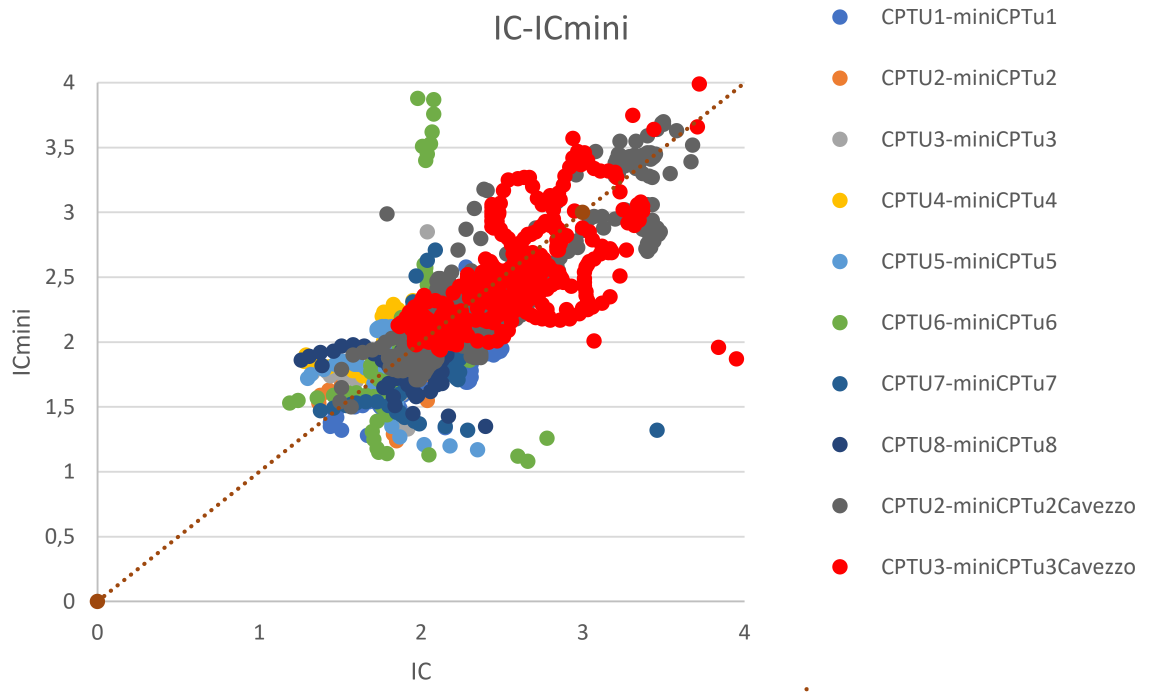


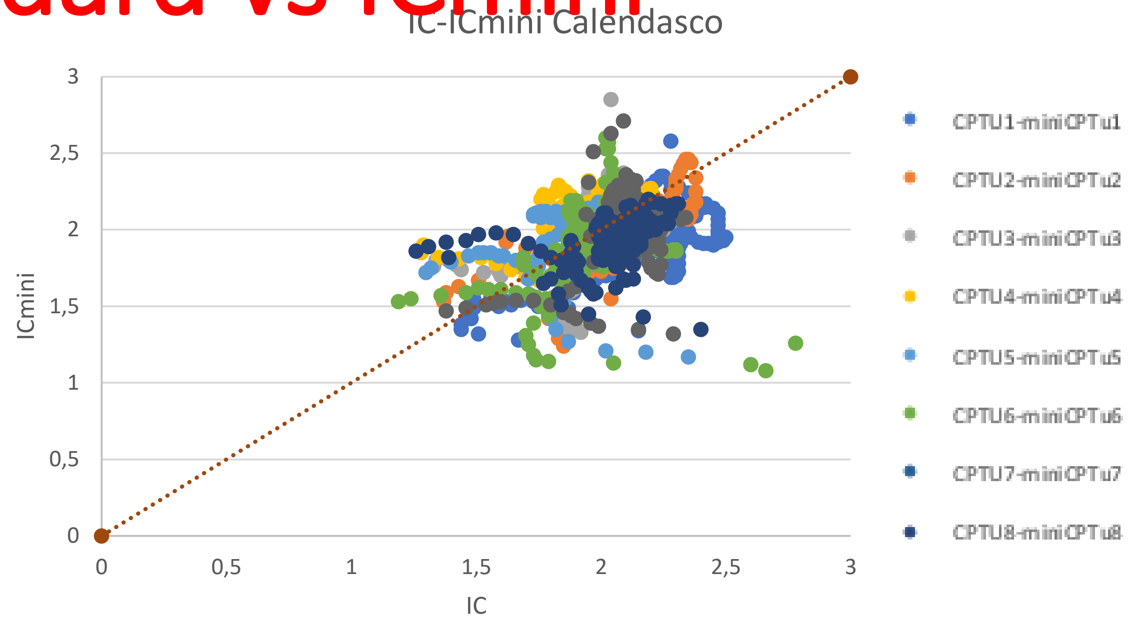


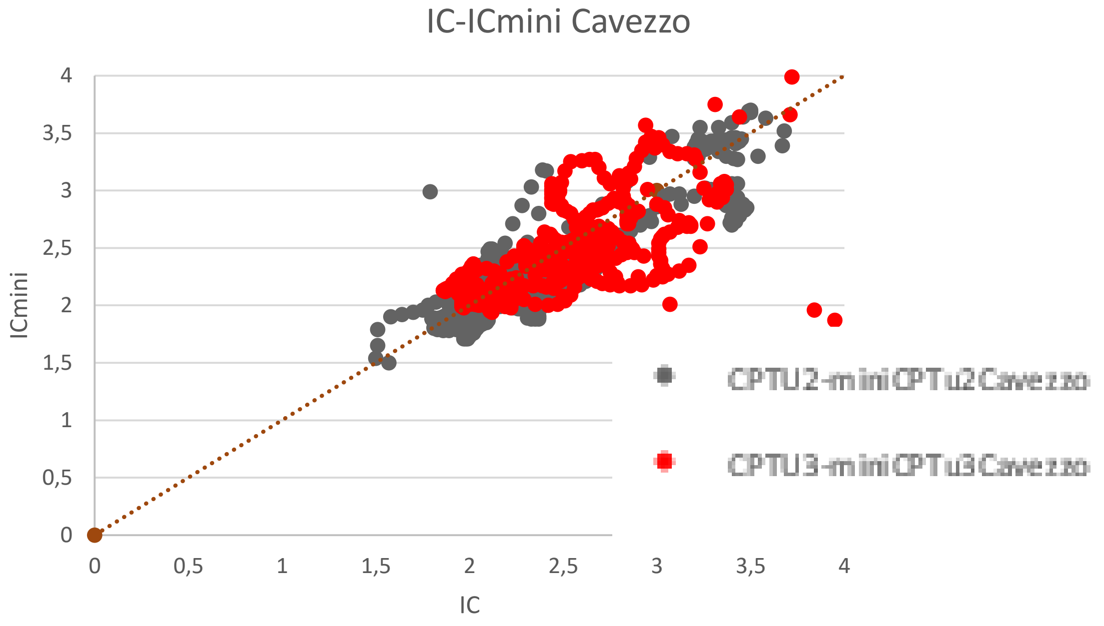
0,8-4,6 m: $\Delta < 50$kPa (fsstandard>fs mini)

4,6-9,4 m: small differences (fsstandard<fs mini)

7. RESULTS – Site B – IC standard vs ICmini

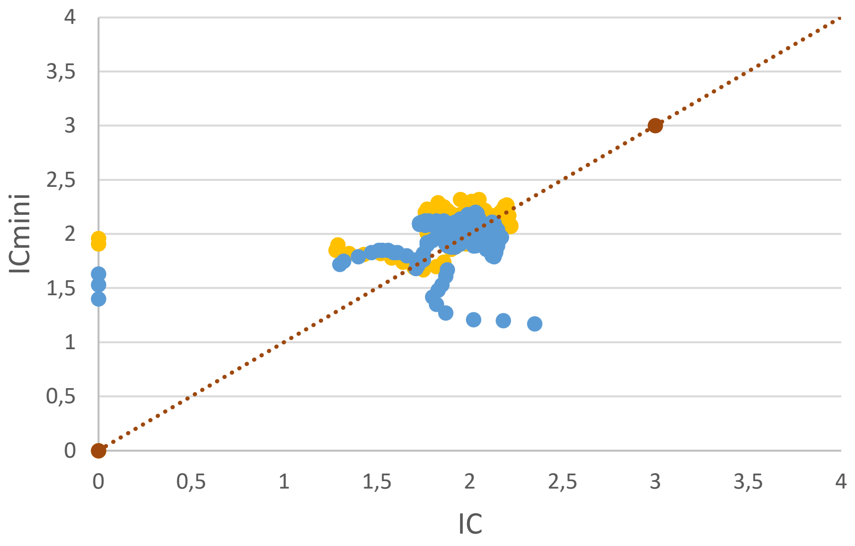




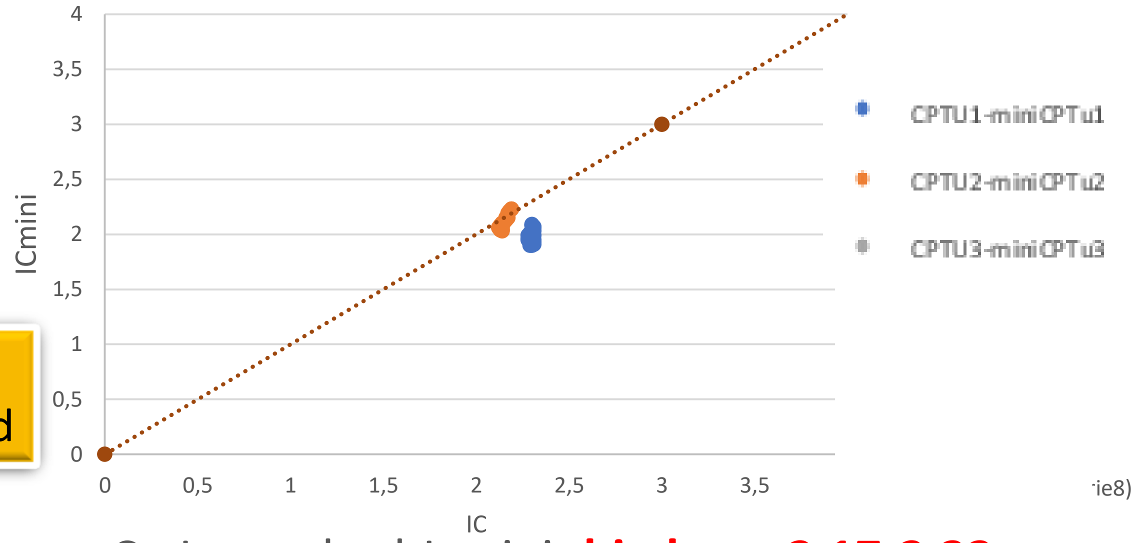


7. RESULTS – Site A – IC standard vs ICmini

B - Icstandard-Icmini **no thin layer**

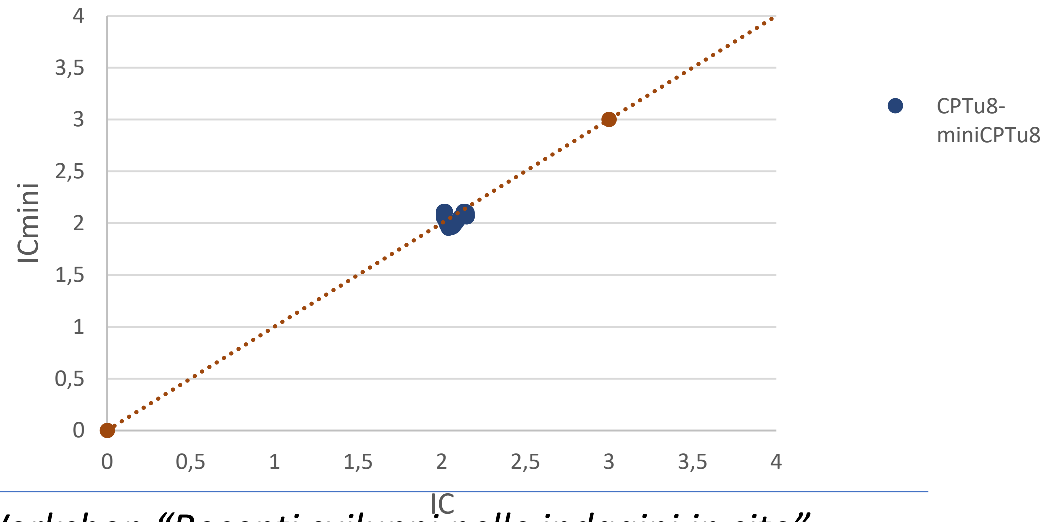


A - Icstandard-Icmini **thin layer 2,37-2,5**

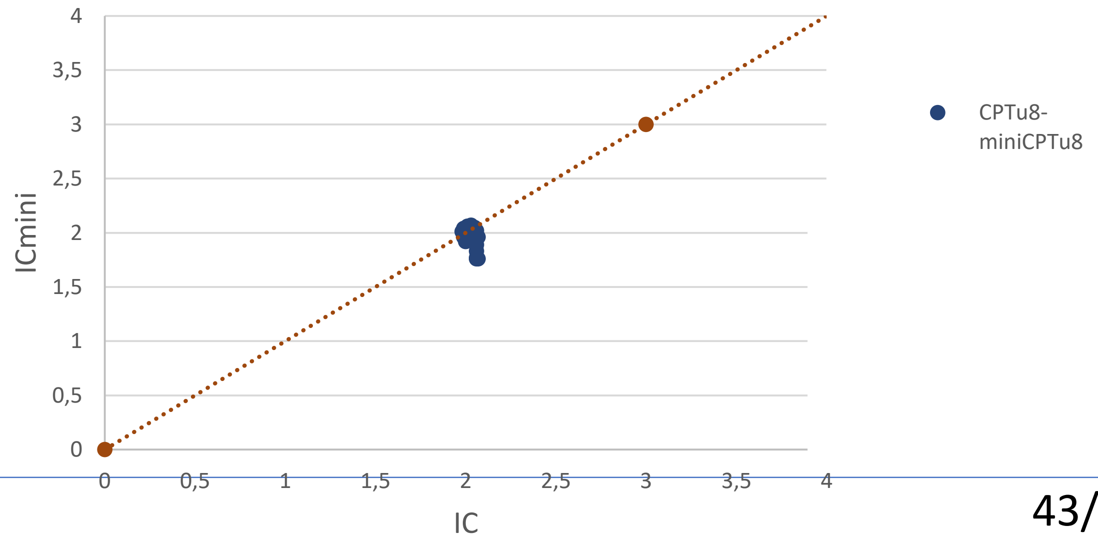


Icmini<=Icstandard
In thin layers of sand

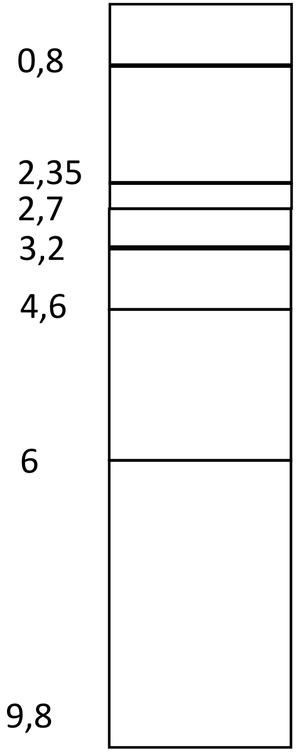
C - Icstandard-ICmini **thin layer1,65-2**



C - Icstandard-Icmini **thin layer 2,17-2,33**



7. RESULTS – Site B - IC vs ICmini



Man made deposits

Silt with clay

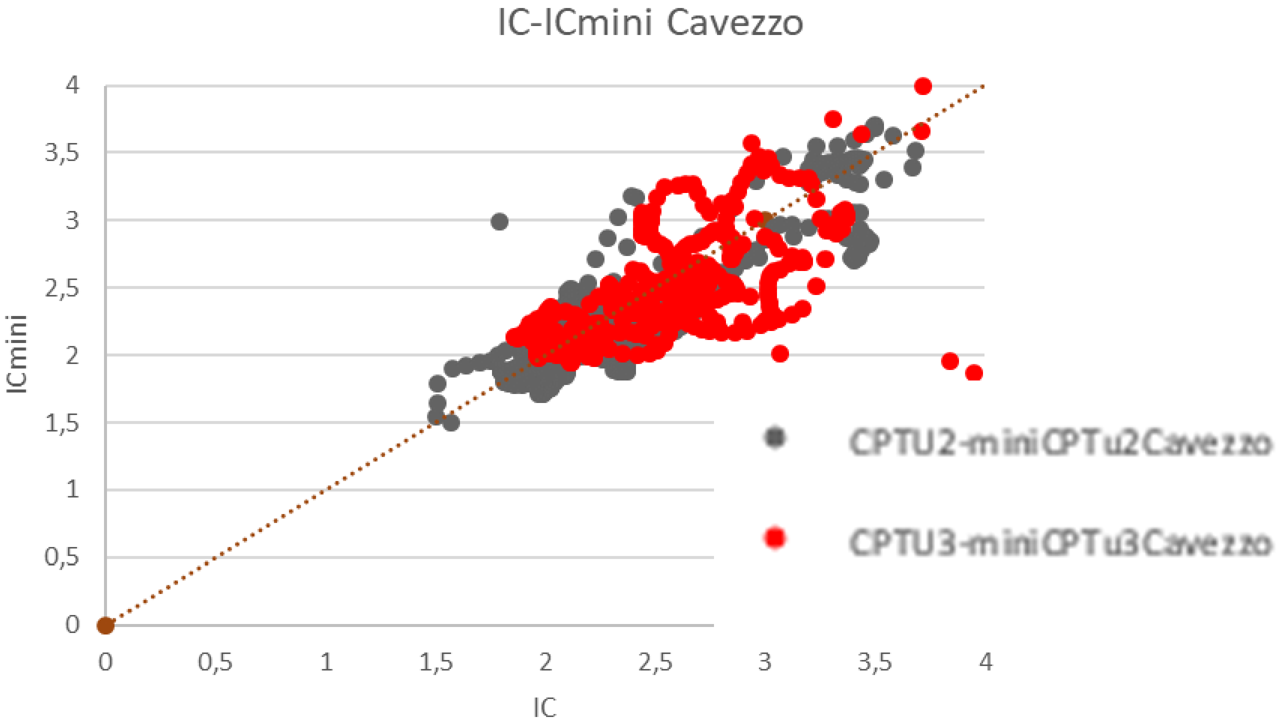
Sandy clay silt

Clay sandy silt with interbedded clay silt

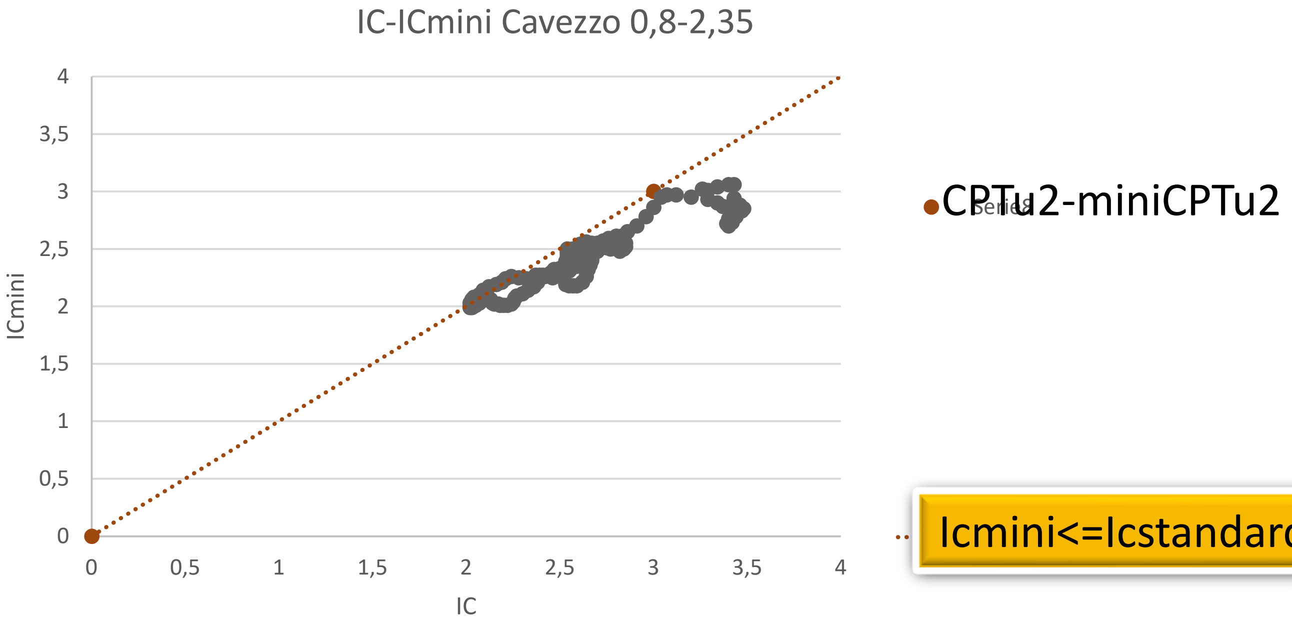
Fine sand with silt

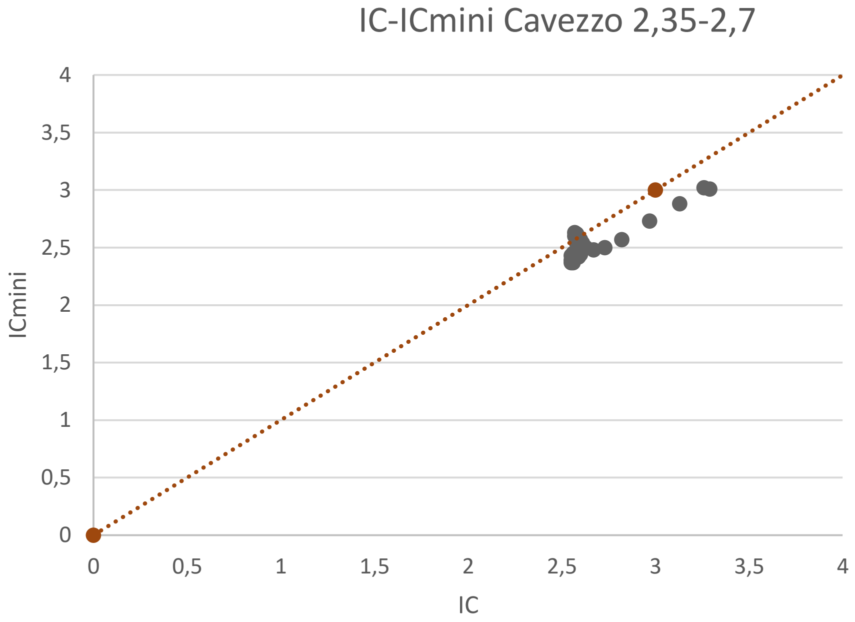
Sily fine grained sand

Medium grained sand with silty layers

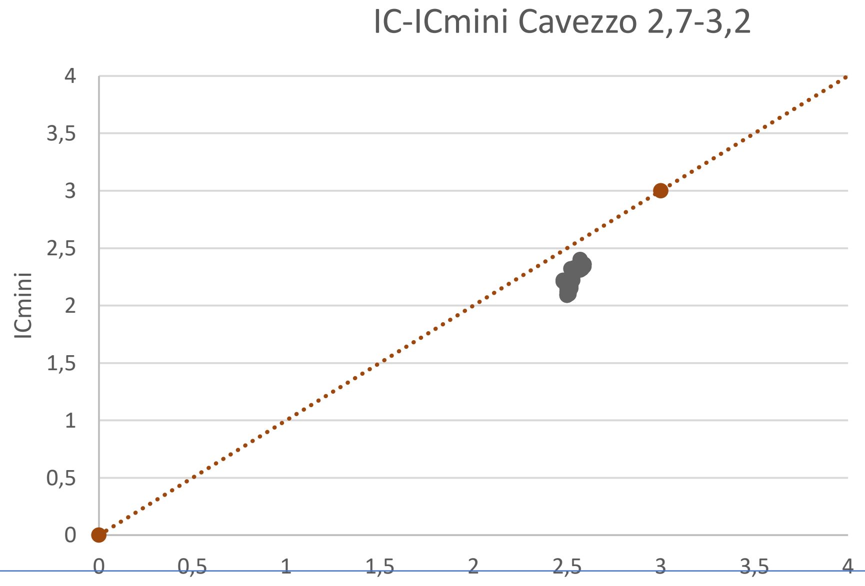


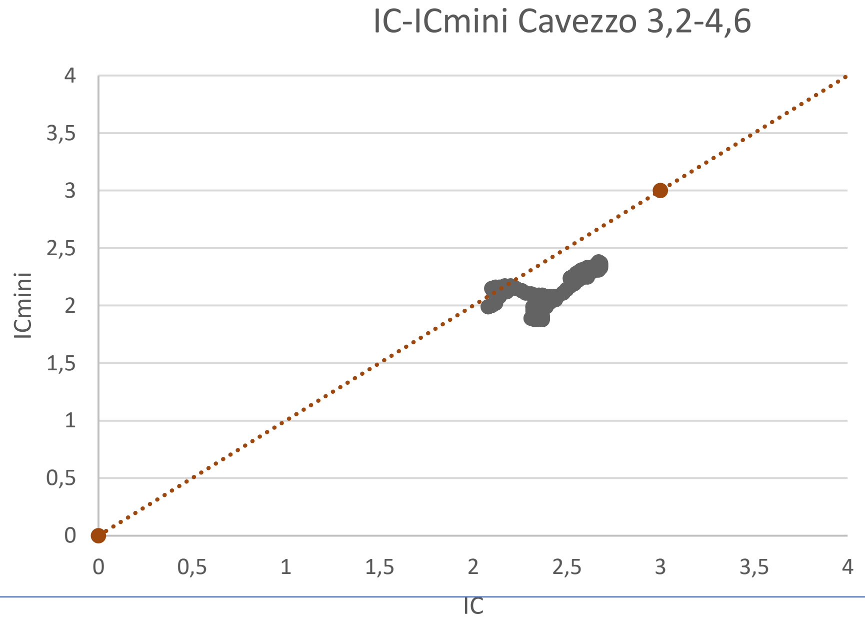
7. RESULTS – Site B – IC standard vs ICmini



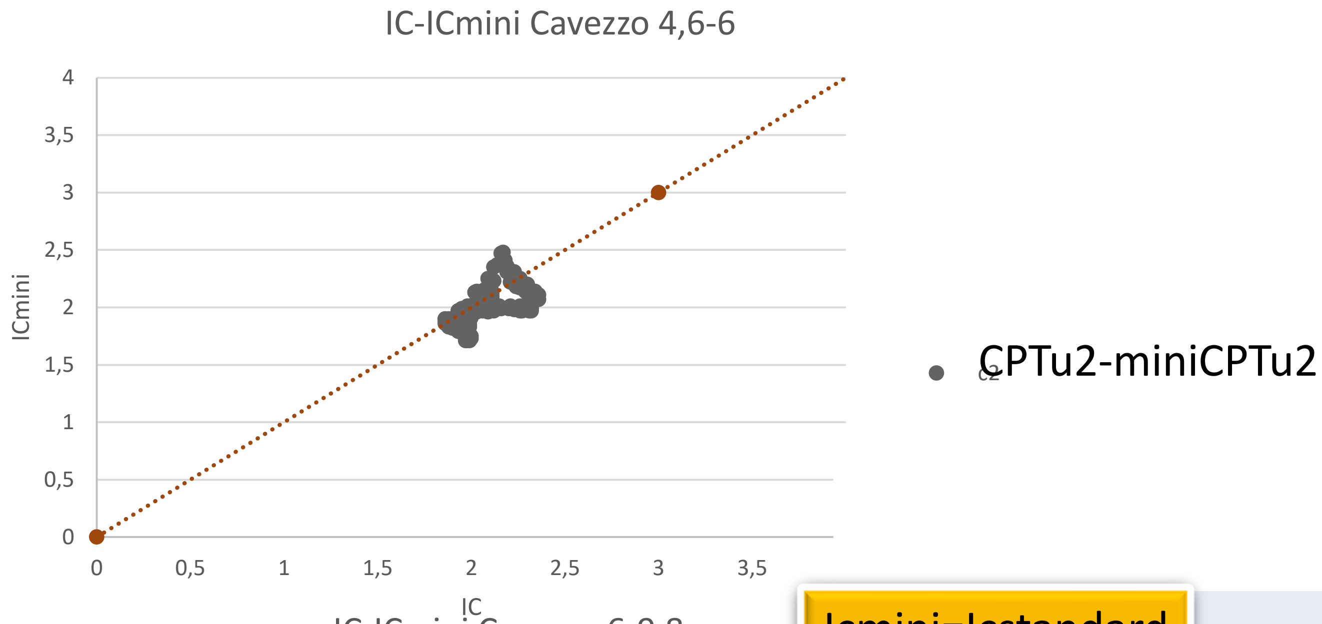


Icmini<=Icstandard

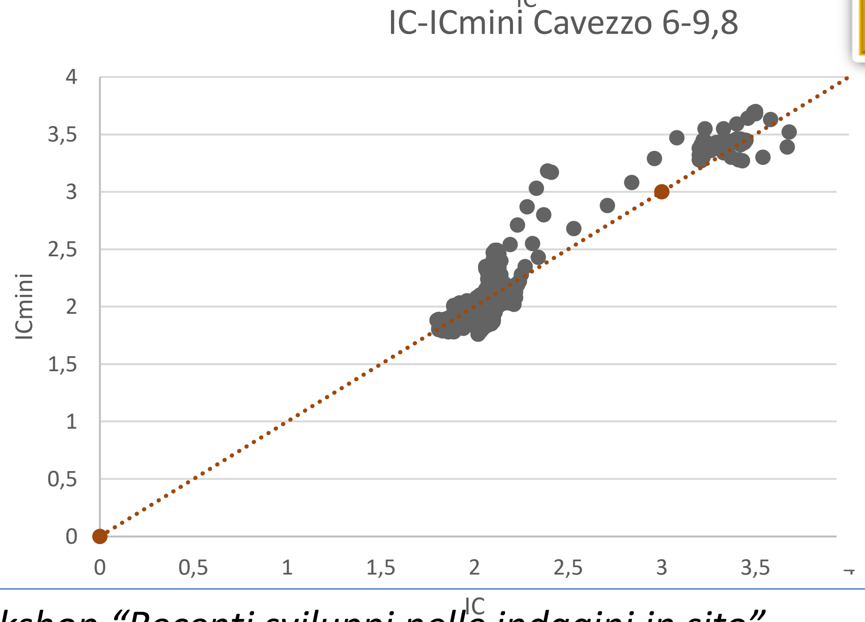




7. RESULTS – Site B – Icstandard vs Icmini



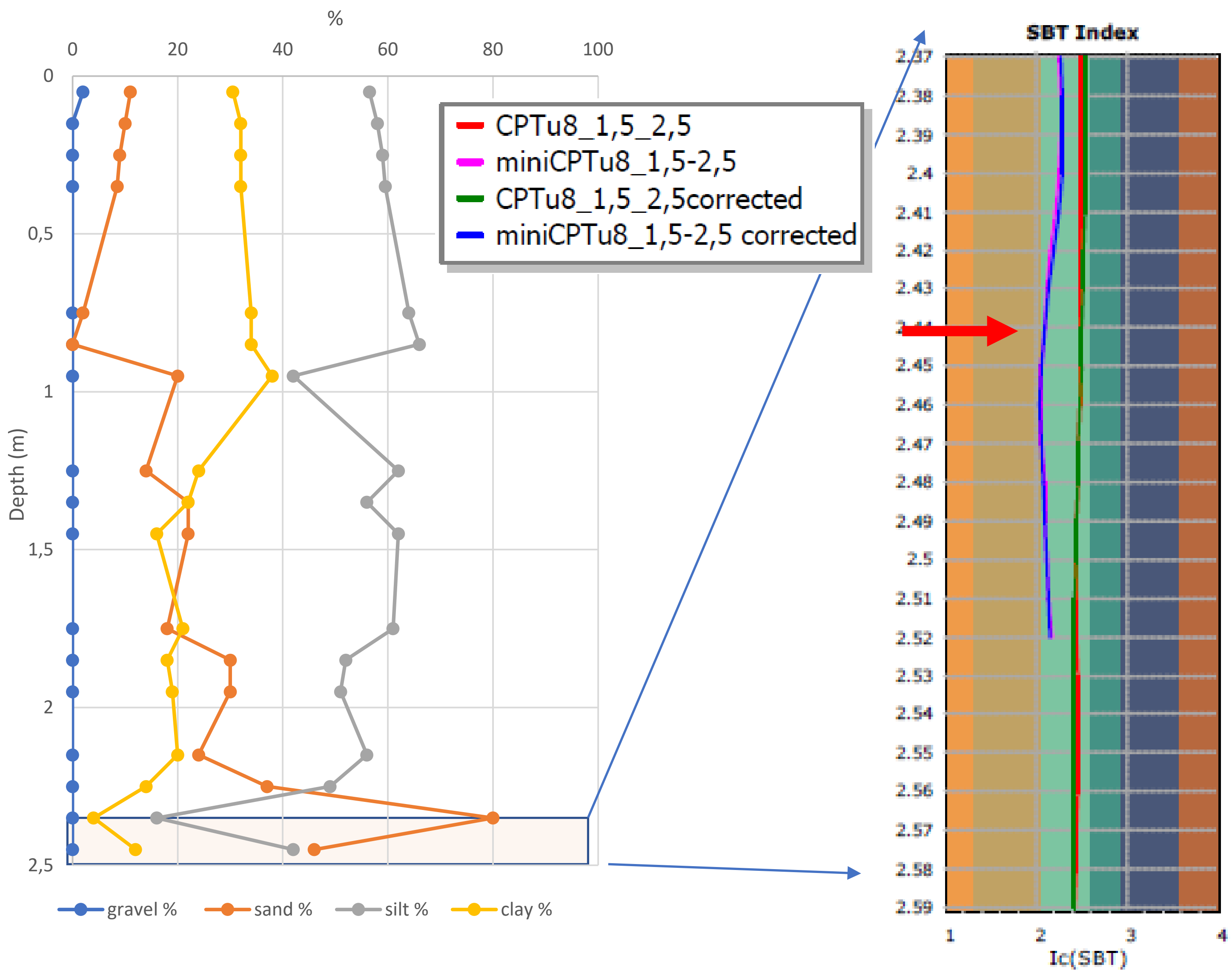
Icmini>=Icstandard



Icmini=Icstandard

Layer (m)	Icmini/Icstandard			
	Average	SD	Min	Max
2,35-2,7	0,95	0,07	0,79	1,67
2,7-3,2	0,88	0,03	0,84	0,93
3,2-4,6	0,88	0,05	0,79	1,02
4,6-6	0,96	0,06	0,85	1,14
6-9,4	1,01	0,07	0,87	1,33

7. RESULTS – TEST SITE A - thin layer correction



Thin layer correction (Boulanger and De Jong , 2018)

CLIQ

The thin layer correction of standard CPTu doesn’t allow to detect the thin layer of sand

Mini CPTu detect the thin layer of sand

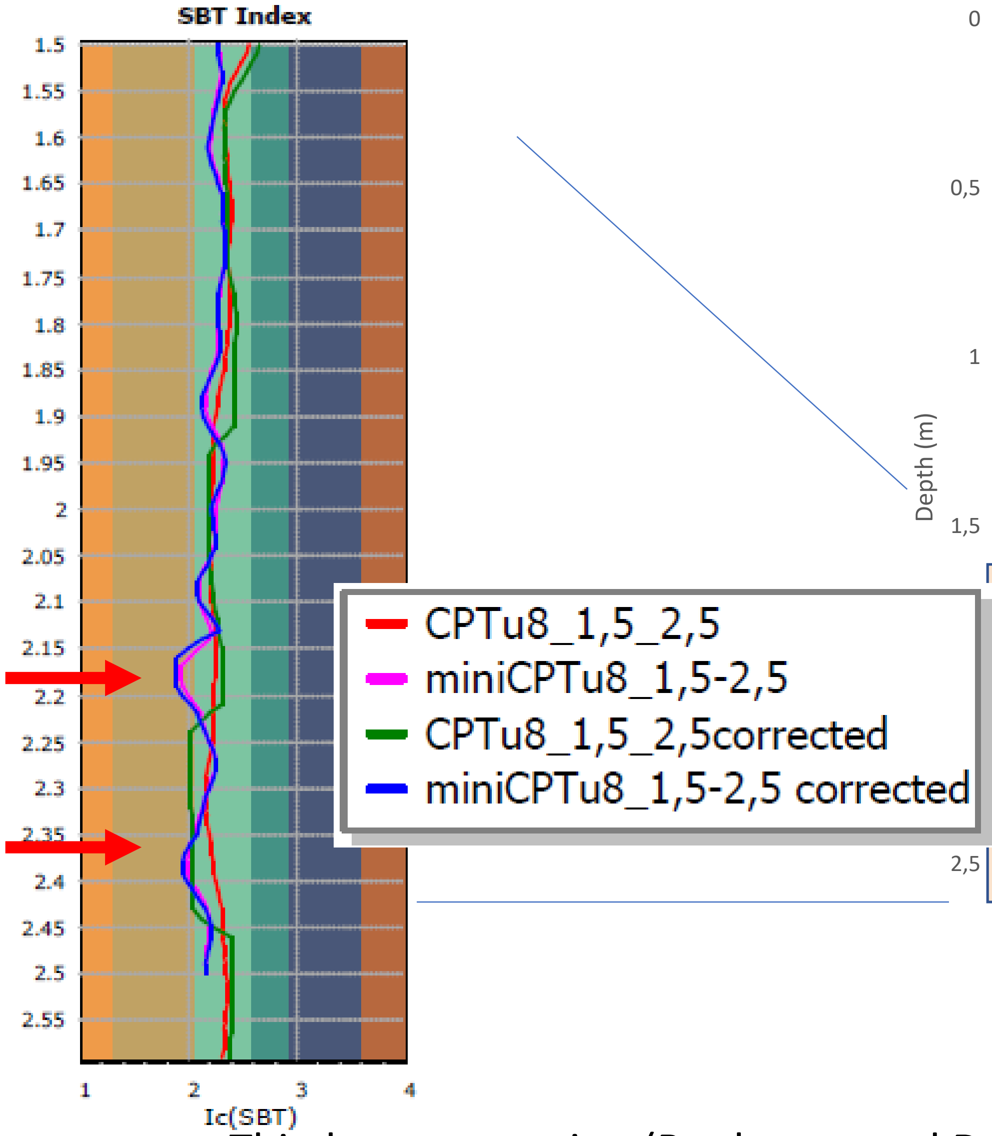
The application of the thin layer correction to mini CPTu does not change the results

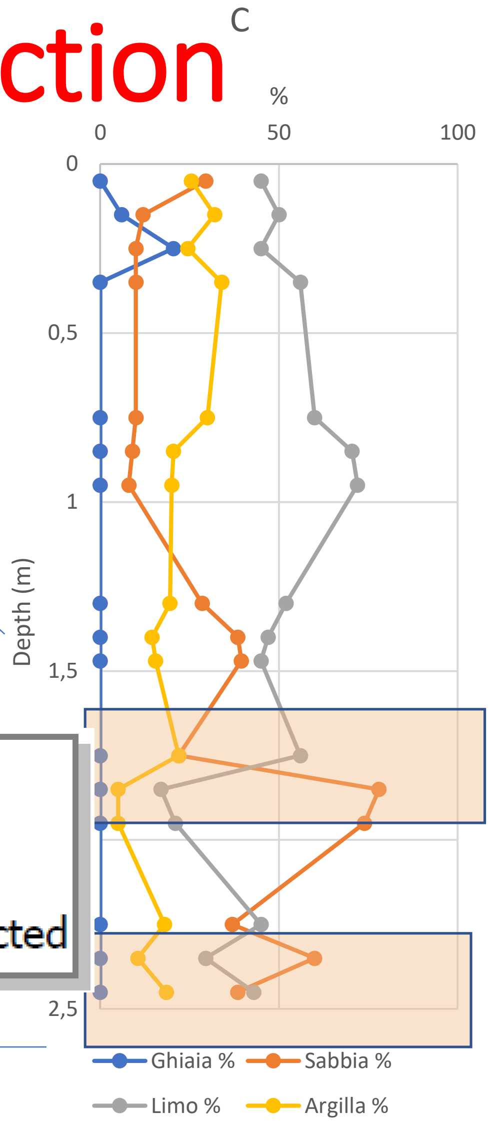
7. RESULTS – TEST SITE A - thin layer correction

Thin layer 1,65-2m
Not identified by standard CPTu and mini CPTu (corrected and no corrected)

Thin layer 2,17-2,35m

- The corrected standard CPTu identifies the thin layer (different depth)
- Mini CPTu detects the thin layer of sand
- The application of the thin layer correction to mini CPTu does not change the results





Thin layer correction (Boulanger and De Jong , 2018)

7. RESULTS – TEST SITE A - thin layer correction

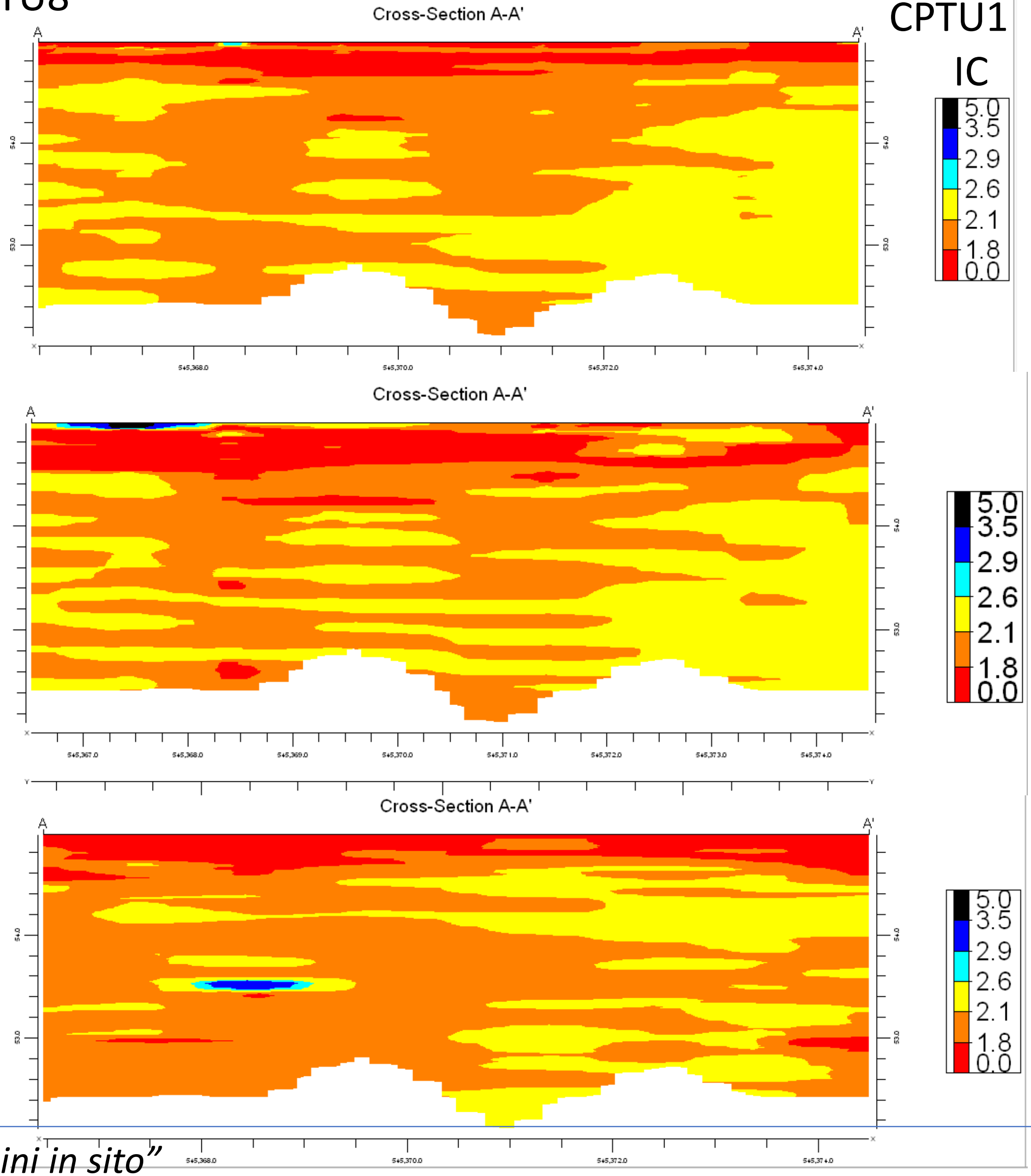
CPTU8

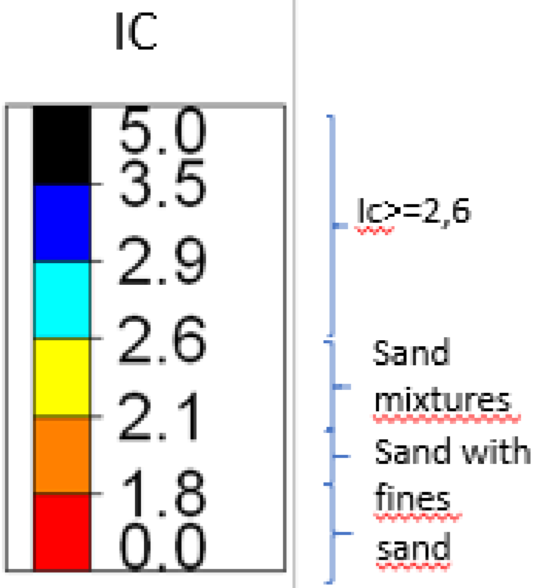
CPTU1

CPTu

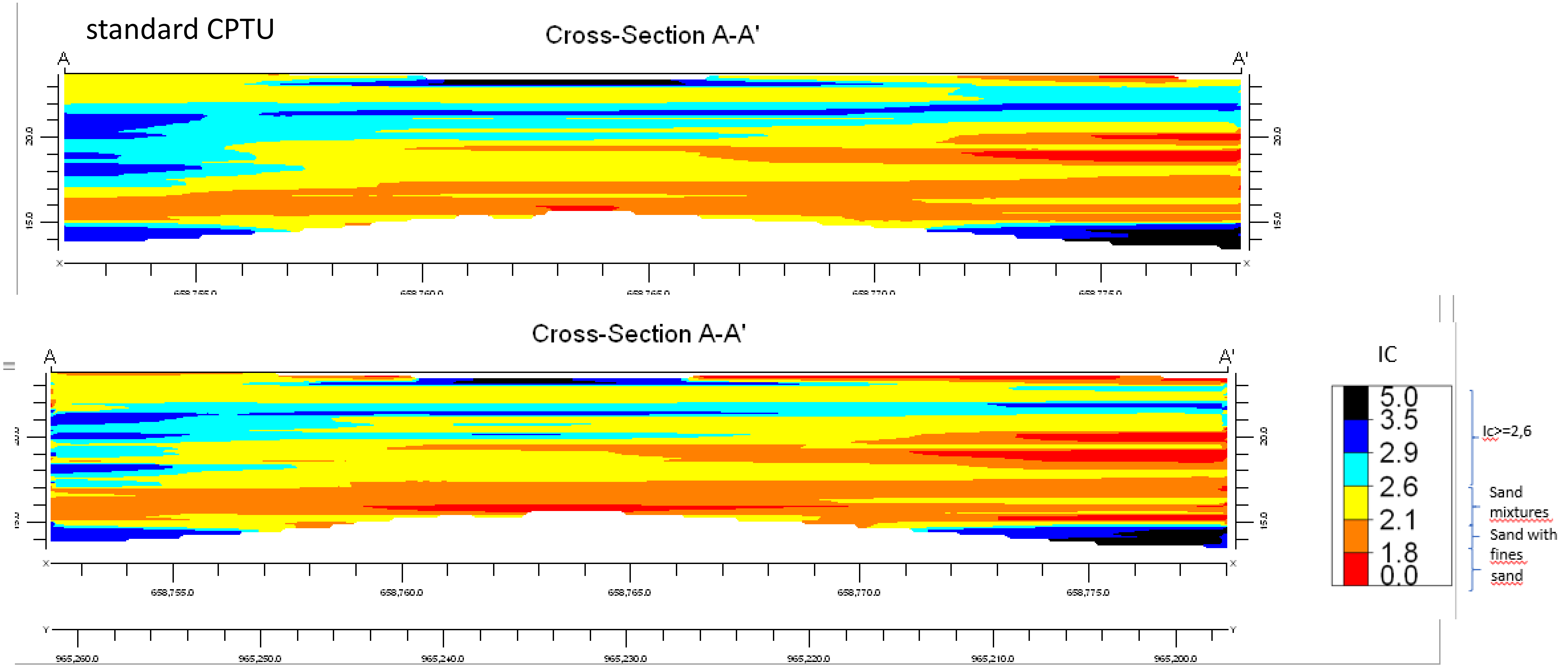
CPTu with thin layer correction

Mini-CPTu





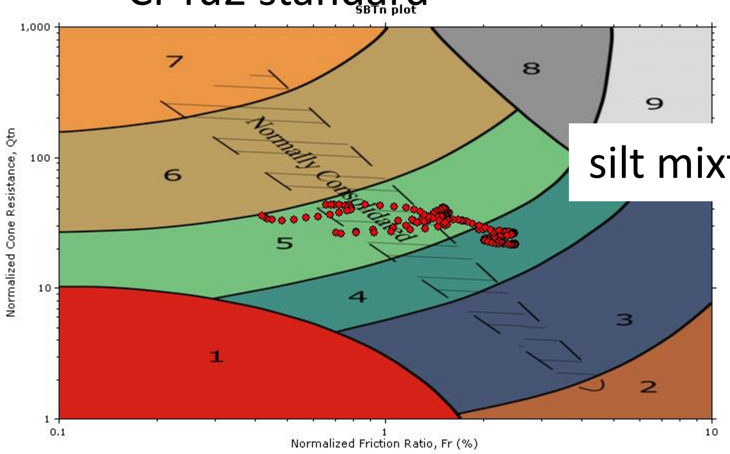
7. RESULTS – TEST SITE B - thin layer correction



standard CPTU with thin layer correction

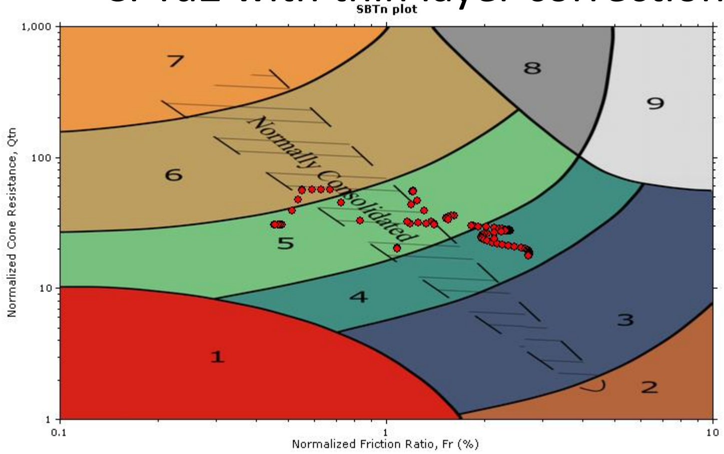
7. RESULTS – TEST SITE B – CPTu vs corrected CPTu vs mini-CPTu vs corrected mini CPTu

CPTu2 standard



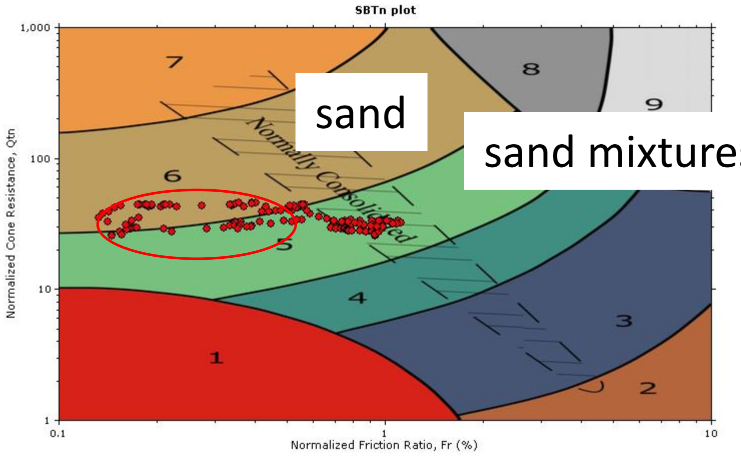
silt mixtures

CPTu2 with thin layer correction



LAYER 3,2-4,6 m

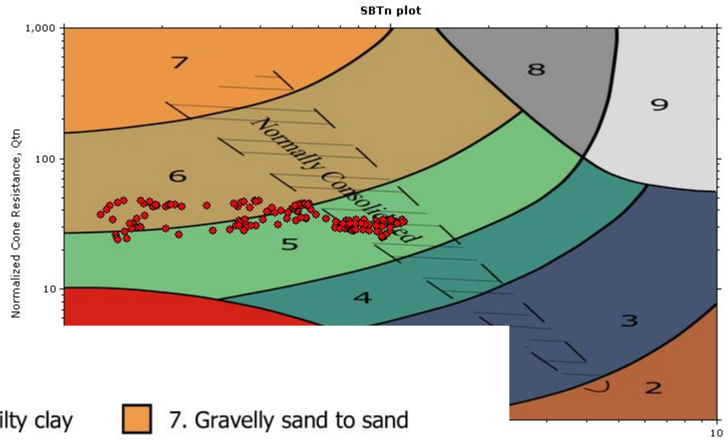
Mini – CPTu2



sand

sand mixtures

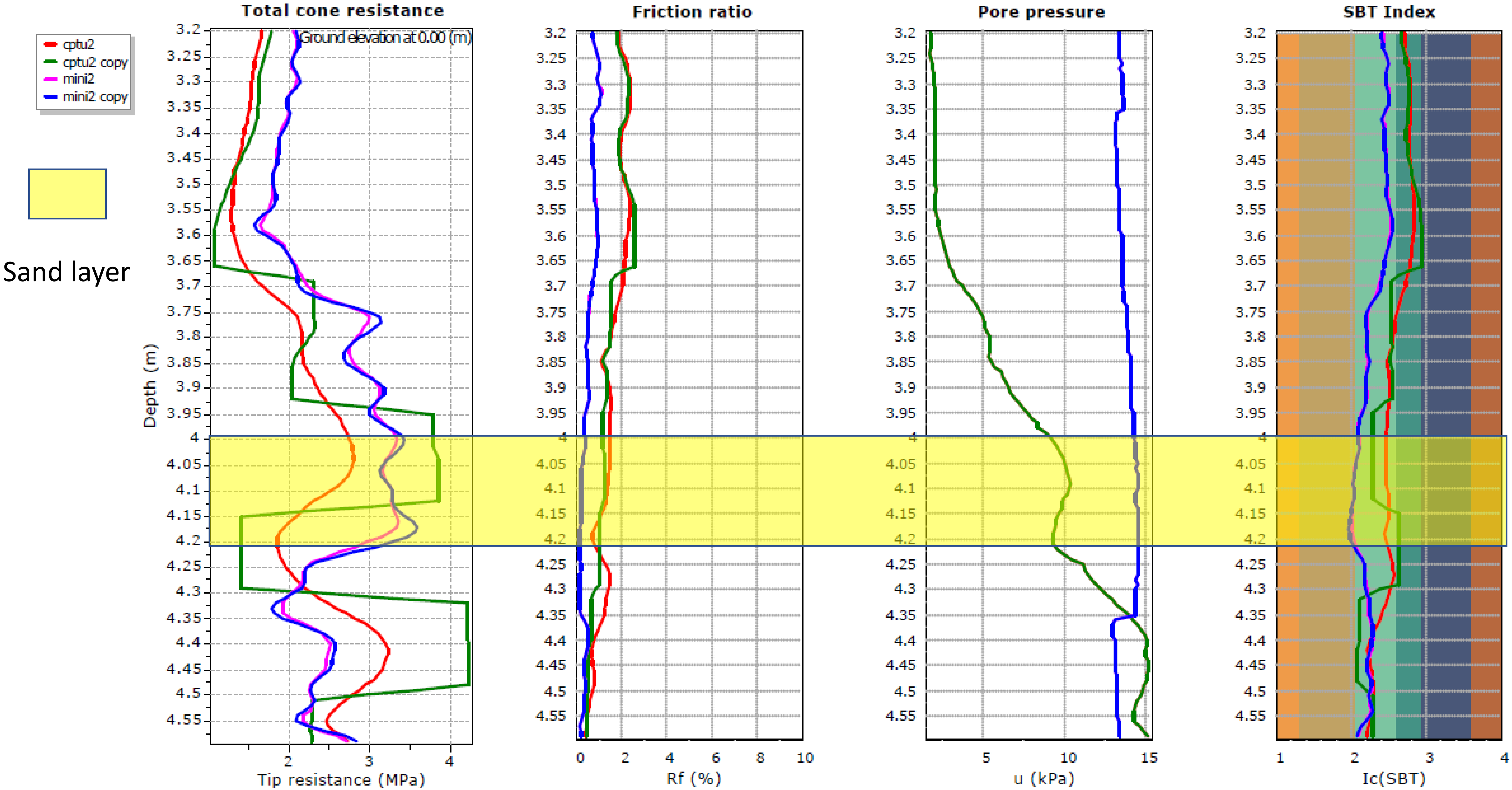
Mini – CPTu2 with thin layer correction



SBTn legend

- 1. Sensitive fine grained
- 2. Organic material
- 3. Clay to silty clay
- 4. Clayey silt to silty clay
- 5. Silty sand to sandy silt
- 6. Clean sand to silty sand
- 7. Gravelly sand to sand
- 8. Very stiff sand to clayey sand
- 9. Very stiff fine grained

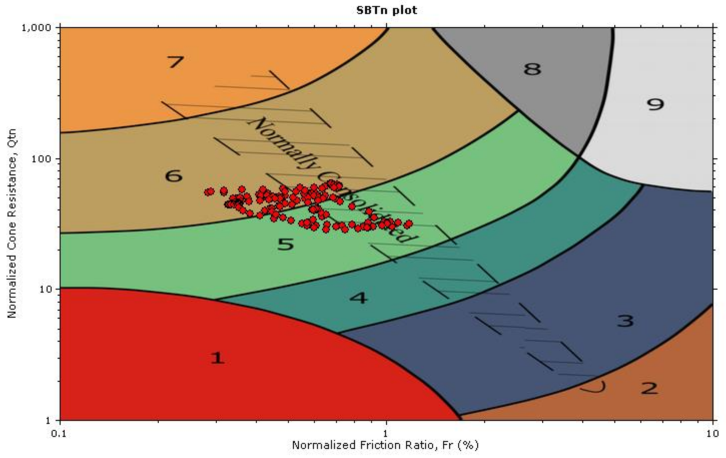
LAYER 3,2-4,6 m



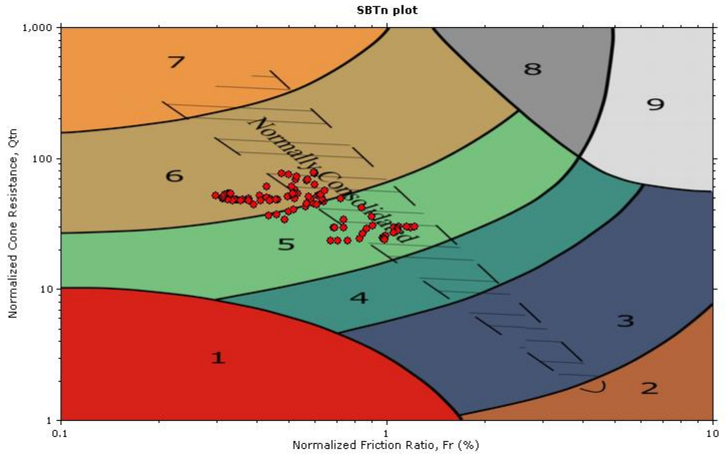
Total cone resistance
Ground elevation at 0.00 (m)
cptu2
cptu2 copy
mini2
mini2 copy
Depth (m)
Tip resistance (MPa)
Friction ratio
Rf (%)
Pore pressure
u (kPa)
SBT Index
Ic(SBT)
Sand layer

7. RESULTS – TEST SITE B – CPTu vs corrected CPTu vs mini-CPTu vs corrected mini CPTu

CPTu2 standard

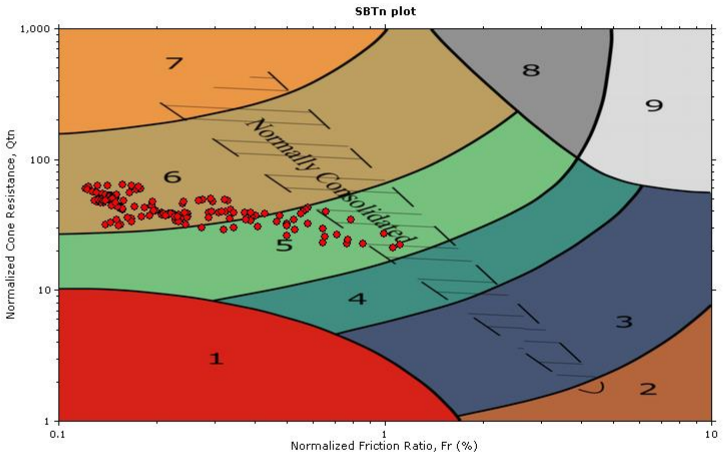


CPTu2 with thin layer correction

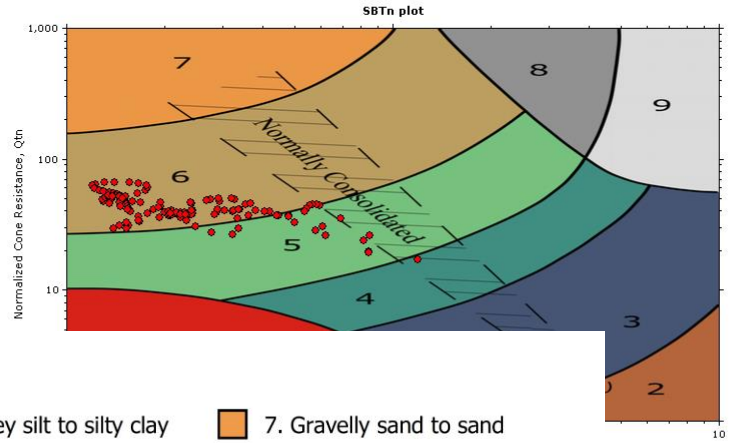


LAYER 4,6-6 m

Mini – CPTu2



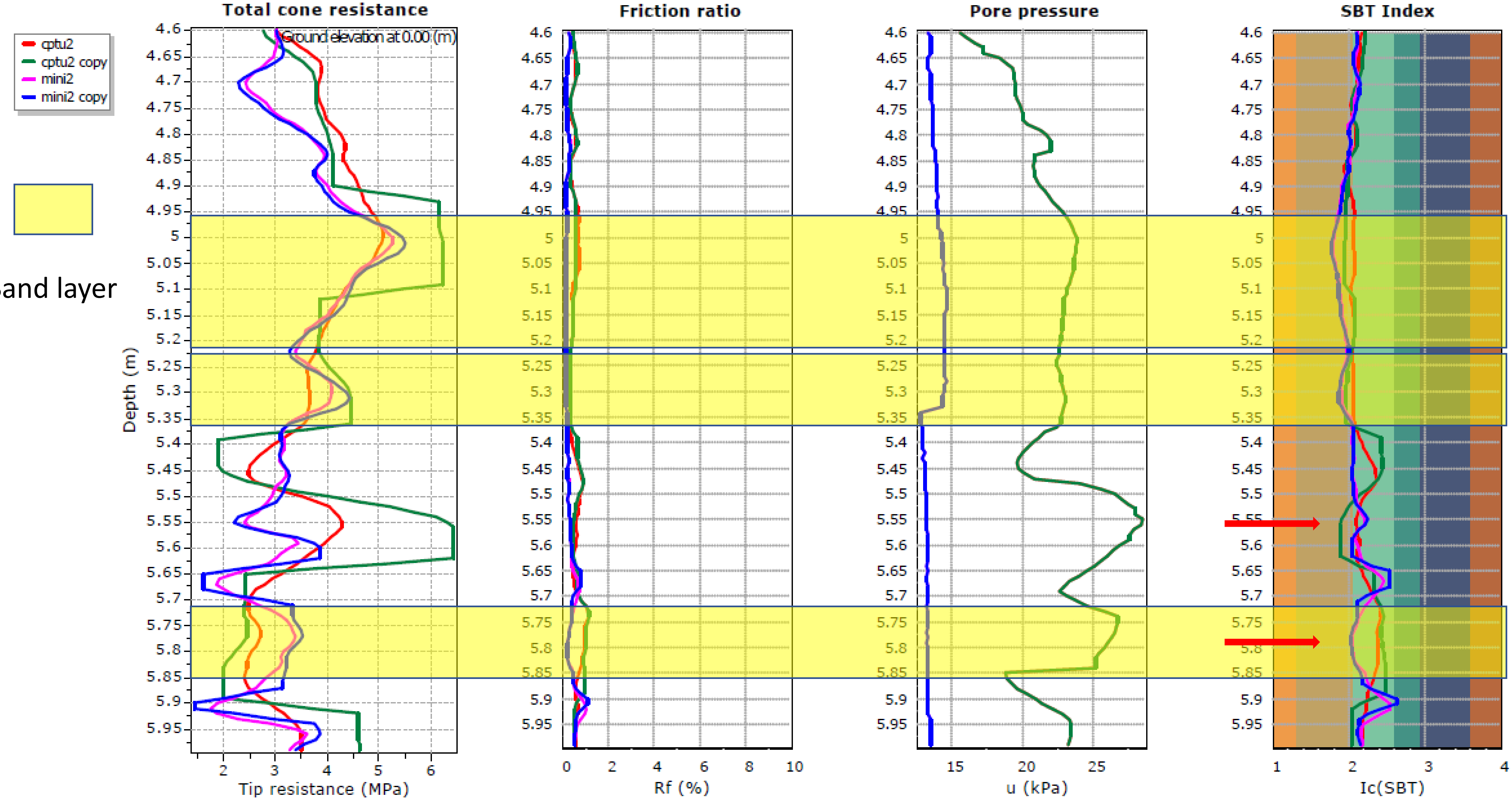
Mini – CPTu2 with thin layer correction



SBTn legend

- 1. Sensitive fine grained
- 2. Organic material
- 3. Clay to silty clay
- 4. Clayey silt to silty clay
- 5. Silty sand to sandy silt
- 6. Clean sand to silty sand
- 7. Gravelly sand to sand
- 8. Very stiff sand to clayey sand
- 9. Very stiff fine grained

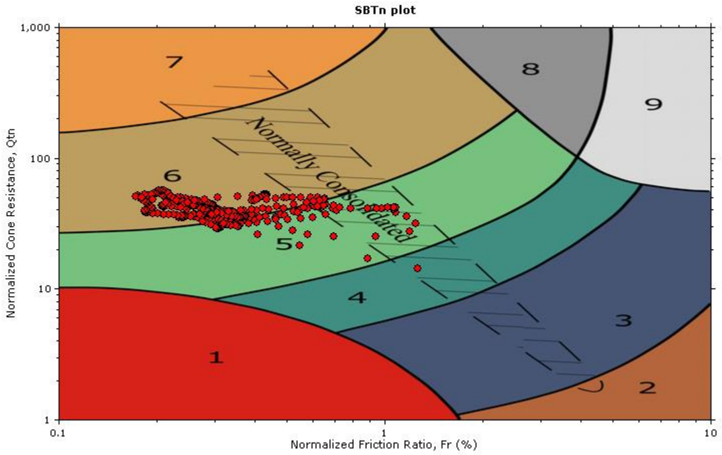
LAYER 4,6-6 m



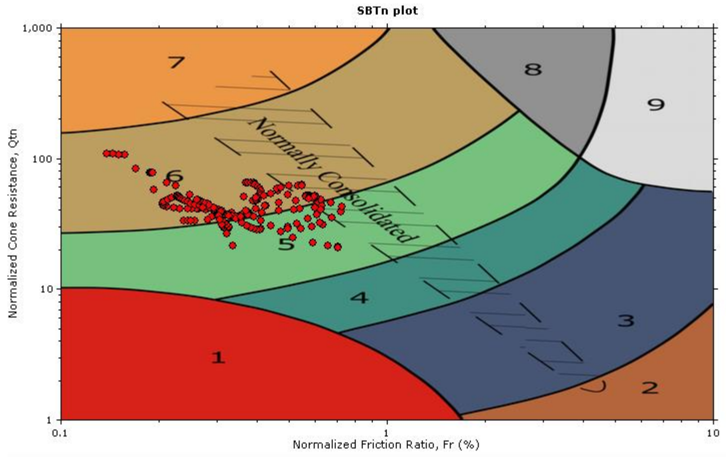
Sand layer

7. RESULTS – TEST SITE B – CPTu vs corrected CPTu vs mini-CPTu vs corrected mini CPTu

CPTu2 standard

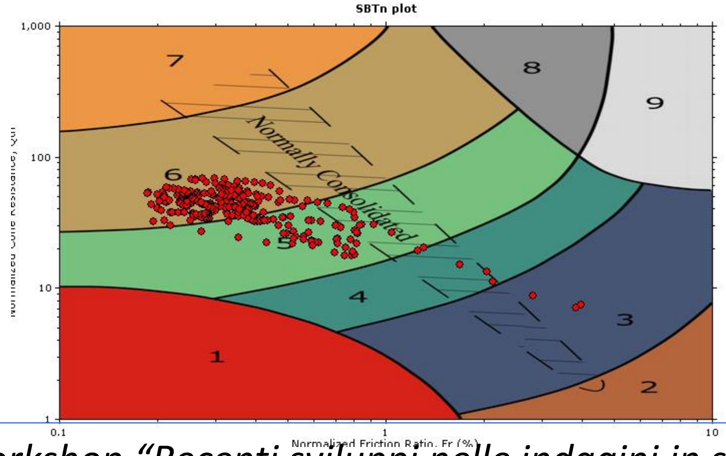


CPTu2 with thin layer correction

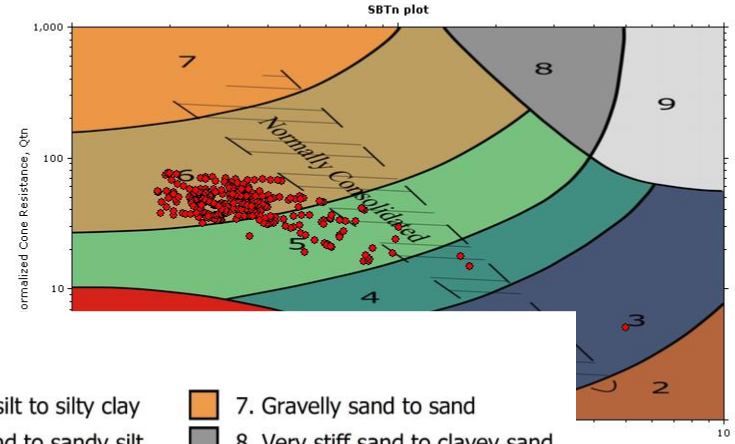


LAYER 6-9,3m

Mini – CPTu2



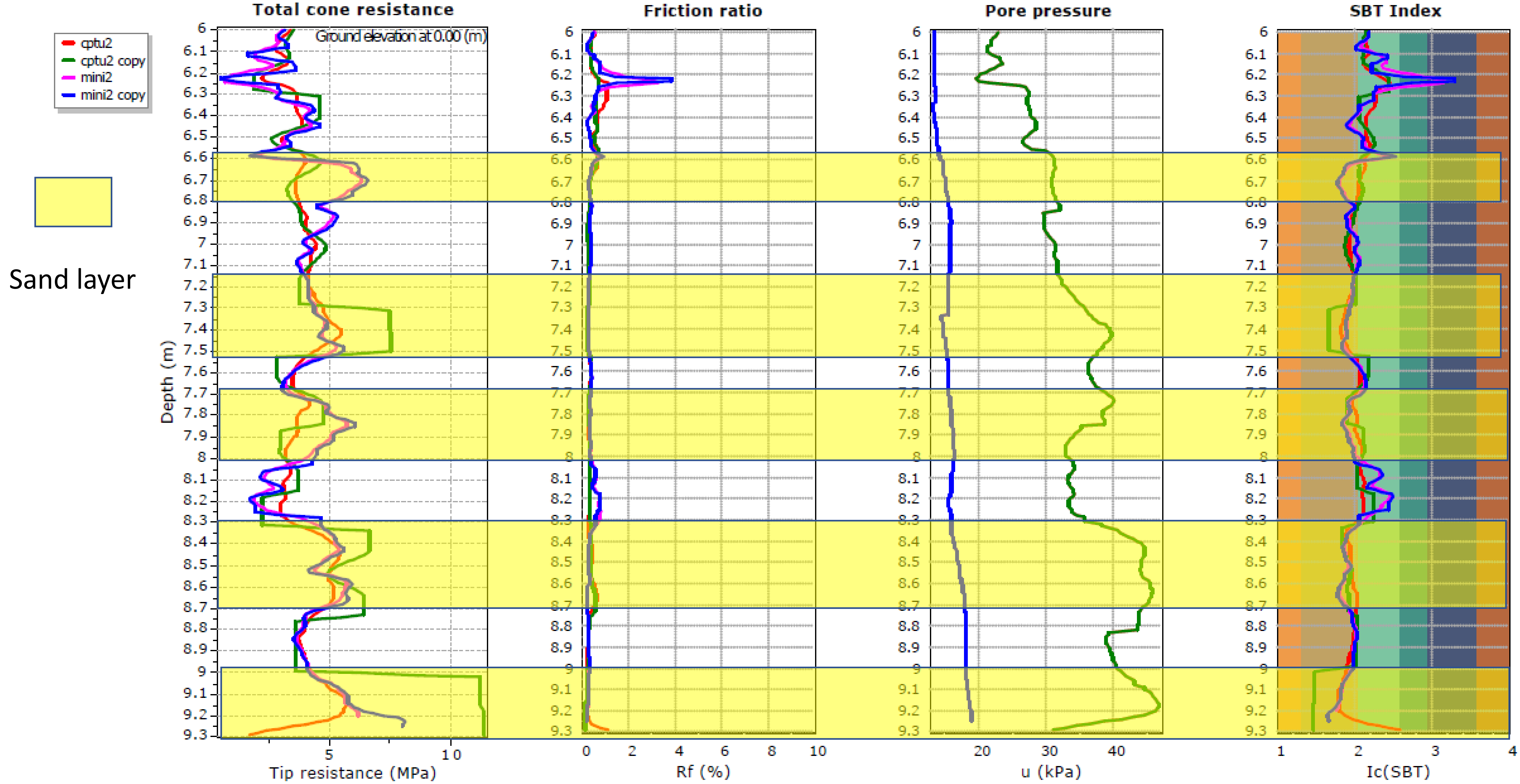
Mini – CPTu2 with thin layer correction



SBTn legend

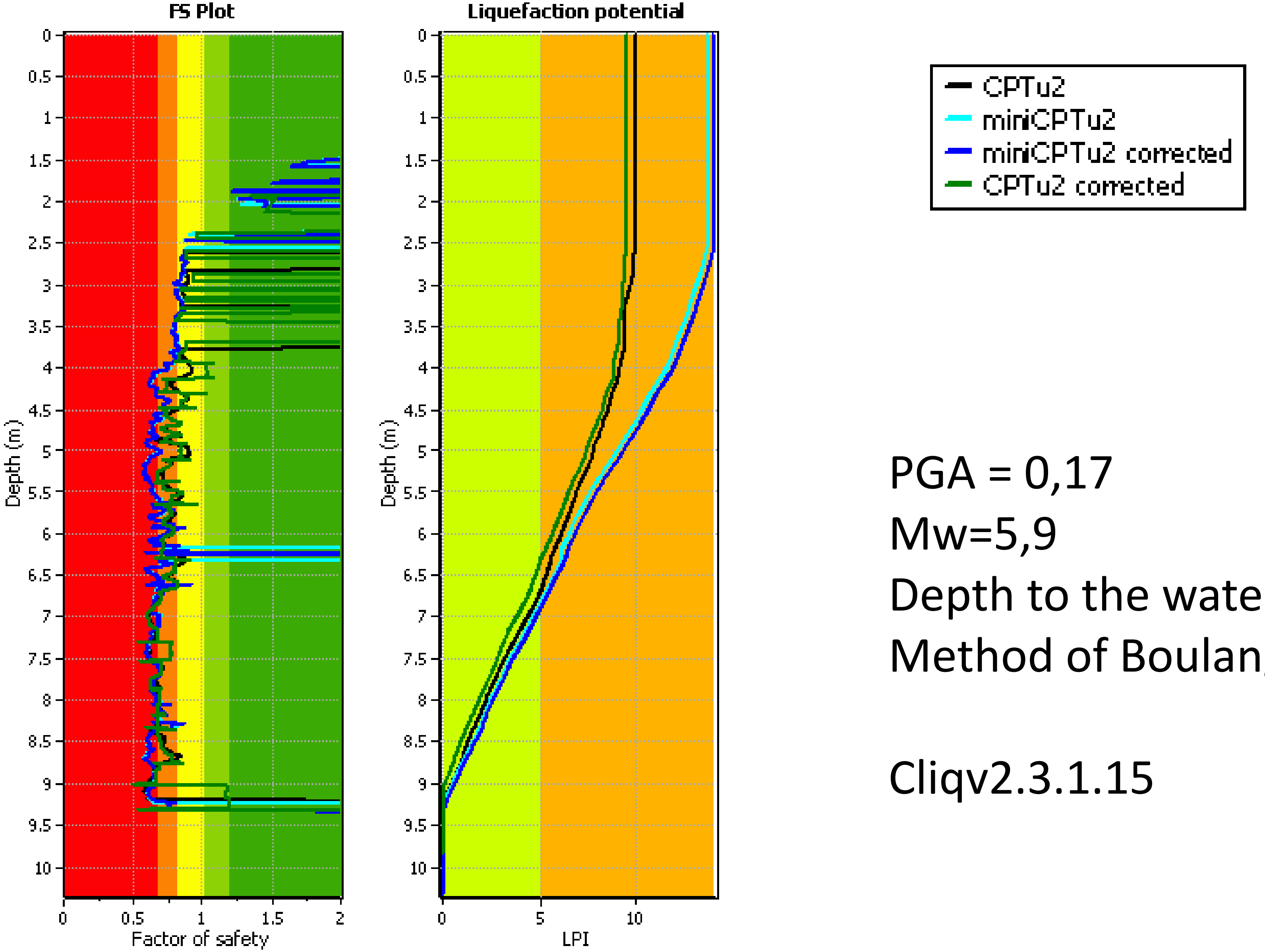
- 1. Sensitive fine grained
- 2. Organic material
- 3. Clay to silty clay
- 4. Clayey silt to silty clay
- 5. Silty sand to sandy silt
- 6. Clean sand to silty sand
- 7. Gravelly sand to sand
- 8. Very stiff sand to clayey sand
- 9. Very stiff fine grained

LAYER 6-9,3m



Total cone resistance
Ground elevation at 0.00 (m)
cptu2
cptu2 copy
mini2
mini2 copy
Depth (m)
Tip resistance (MPa)
Friction ratio
Rf (%)
Pore pressure
u (kPa)
SBT Index
Ic(SBT)
Sand layer

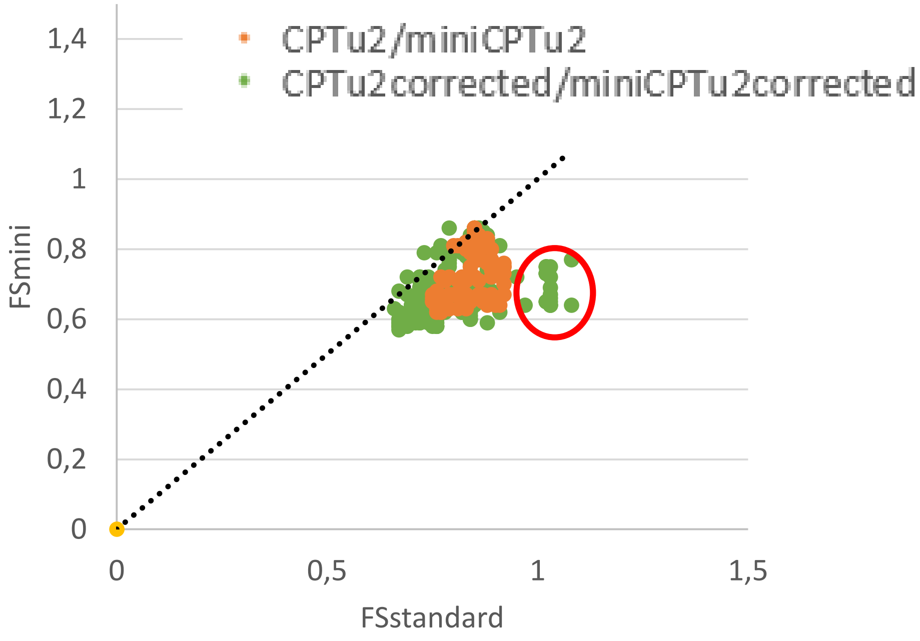
7. RESULTS – TEST SITE B – liquefaction potential (LPI)



PGA = 0,17
Mw=5,9
Depth to the water table = 2,1 m
Method of Boulanger and Idriss, 2014

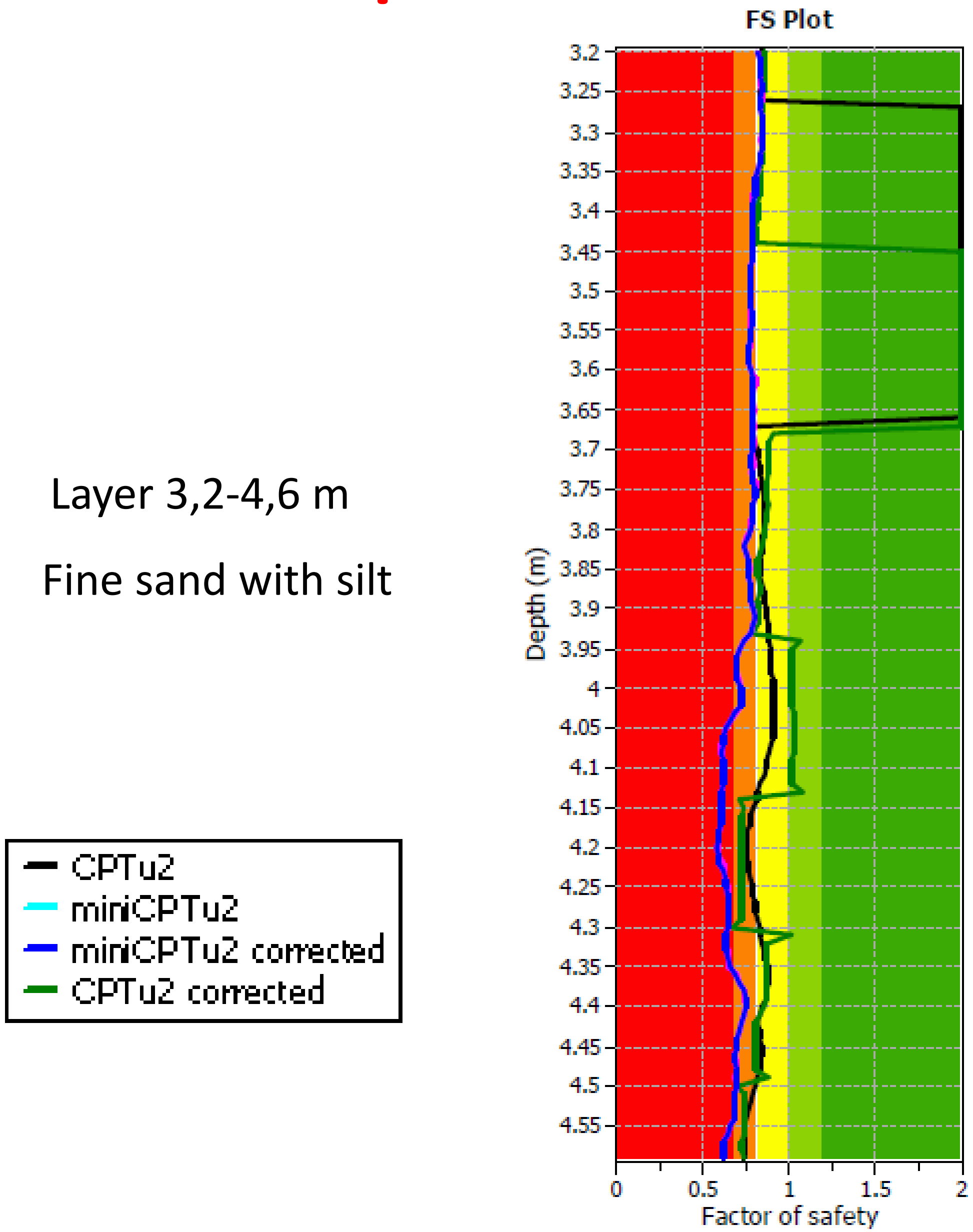
Cliqv2.3.1.15

7. RESULTS – TEST SITE B – liquefaction potential



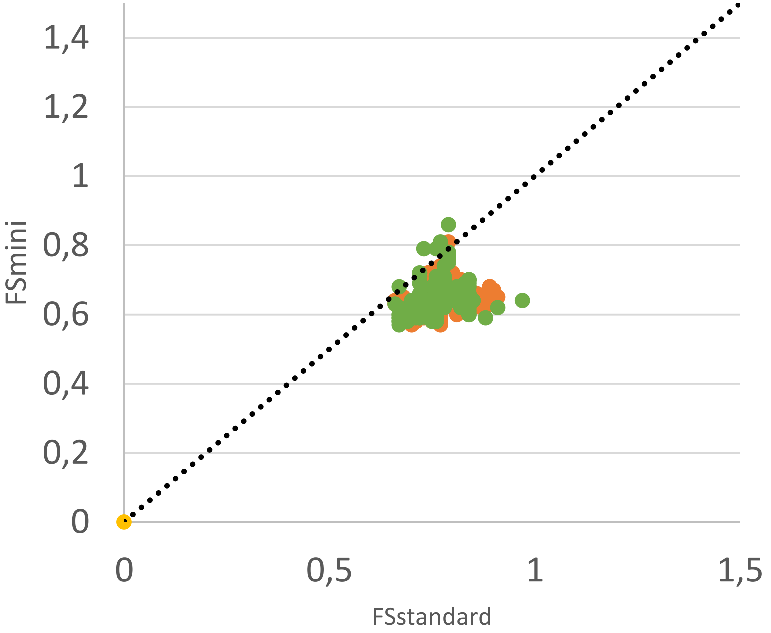
Layer 3,2-4,6 m

Fine sand with silt



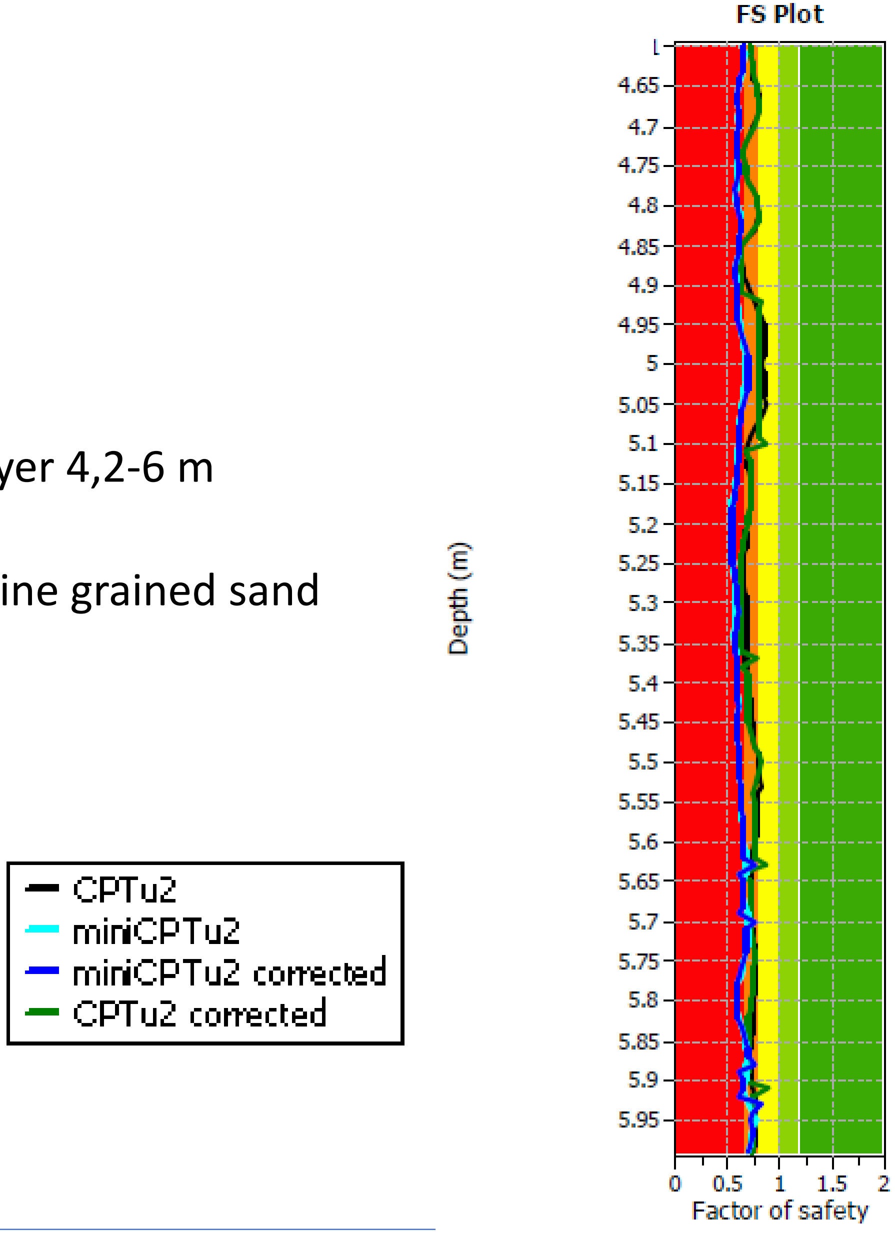
Fsmini≠Fsstandard

7. RESULTS – TEST SITE B – liquefaction potential



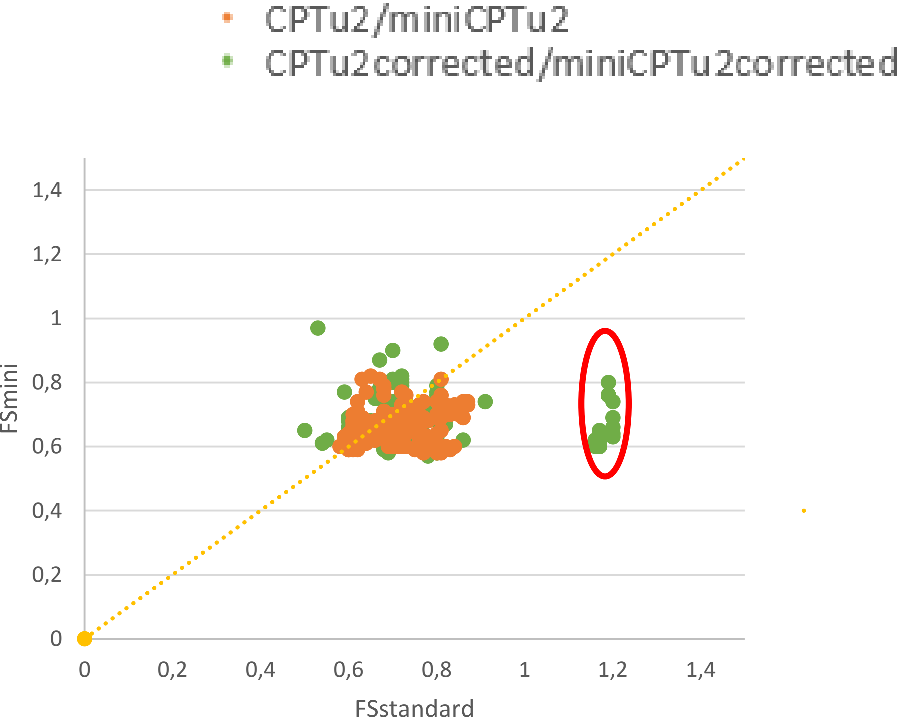
Layer 4,2-6 m

Silty Fine grained sand



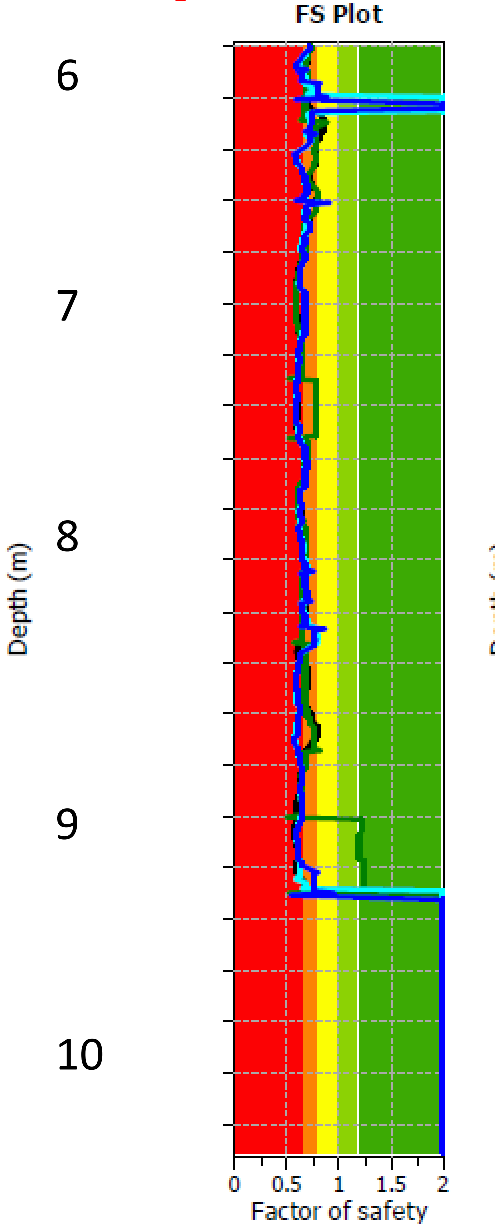
Fsmini=Fsstandard

7. RESULTS – TEST SITE B – liquefaction potential



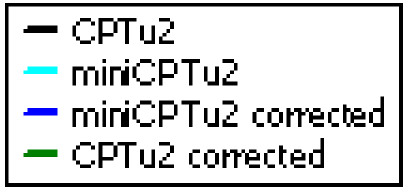
Icmini=Icstandard

Fsmini=Fsstandard



Layer 6-9,3 m

Medium sand with silty layers



8. CONCLUSION

Site A – Calendasco

Thin layer of sand in silty clay

Unsaturated conditions

- ❑ Not systematic differences between qc standard, fsstandard and qcmini, fs mini. In some cases differences are negligible (sometimes 1-2 MPa). Differences are not related to differences in grain size
- ❑ Generally qc standard<qcmini
- ❑ In thin layers Icmini<= Ic standard
- ❑ Thin layers are not detected by standard CPTu; the thin layer correction improves the identification but the depth of the layers is not correct
- ❑ Thin layers are generally detected by miniCPTu, the correction doesn’t improve the identification
- ❑ Overestimation of grain size

Site B – Cavezzo

Thin layers (silty layers in sandy soils and sandy layers in silty soils)

Saturated conditions

- ❑ differences between qc standard, fsstandard and qcmini depends on the lithological layers
- ❑ Sand with silt (3,2-4,6m):
  - ❑ qcstandard<qc mini;
  - ❑ Ic mini<Icstandard
  - ❑ Thin layers are generally detected by miniCPTu but not by standard CPTu
  - ❑ the correction of the standard CPTu doesn’t improve the identification of thin layers
- ❑ silty sand with interbedded sandy layers (4,6-6m)
  - ❑ qcstandard>qc mini;
  - ❑ Ic mini<Icstandard
  - ❑ Thin layers are generally detected by miniCPTu but not by standard CPTu
  - ❑ the correction of the standard CPTu improve the identification of thin layers but it is not in agreement with minicone
- ❑ Sand with interbedded silty layers (6-9,3 m):
  - ❑ qcstandard<qc mini;
  - ❑ Icmini=Icstandard
  - ❑ Thin layers are detected by mini and standard

8. CONCLUSION

- The LPI calculated with mini cone is higher than LPI calculated with standard (from 10 to 15)
- The LPI calculated with standard CPTu does not change with the thin layer correction in the layer 3,2 and 4,6 m (fine sand with silt)
- Differences between FS standard and Fsmini in the layer between 3,2 and 4,6 m (fine sand with silt)

8. CONCLUSION

PRO	CONS
✓ More detailed stratigraphic logging; ✓ Correct thin layers identification; ✓ Very promising for shallow investigations in soils with multiple thin layers (shallow landslides, liquefaction in shallow horizons, etc…) ✓ Smaller and light vehiche is necessary compared to the standard CPT test	✓ Unsaturated conditions in the superficial layers results in an increase of the resistance (overestimation of soil grain size in terms of SBT) ✓ Limited investigation depth (< 10m)

9. FUTURE WORKS

- Other tests in thinly layered soils
- Assessment of correction factors for different thin layer thickness

THANKS FOR THE ATTENTION