

Comune di Carpi

Provincia di Modena

RELAZIONE GEOLOGICA inerente la caratterizzazione e modellazione geologica del sito (6.2.1. NTC 2018)

RELAZIONE GEOTECNICA relativa alle indagini, alla caratterizzazione e alla modellazione geotecnica a supporto della progettazione strutturale (6.2.2. NTC 2018) nonché relativa alla verifica delle opere di fondazione (6.4. NTC 2018)

ANALISI PERICOLOSITÀ SISMICA LOCALE relativa alla caratterizzazione geofisica del volume significativo di terreno (3.2.2 NTC 2018), valutazione dell'azione sismica di riferimento (3.2.3. NTC 2018), Risposta sismica locale e verifica della stabilità nei confronti della liquefazione (7.11.3. NTC 2018)



OGGETTO:

Integrazione alla caratterizzazione geologica, geotecnica e sismica inerente al progetto di ampliamento del nuovo impianto biometano presso l'impianto di compostaggio AIMAG S.p.A., nella località Fossoli del Comune di Carpi



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Rif. 171/20



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**AZIENDA CON SISTEMA
DI GESTIONE QUALITÀ
CERTIFICATO DA DNV
= ISO 9001 =**

RELAZIONE GEOLOGICA

inerente alla caratterizzazione e modellazione geologica del sito (6.2.1 NTC 2018)

RELAZIONE GEOTECNICA

Relativa alle indagini, alla caratterizzazione e alla modellazione geotecnica a supporto della progettazione strutturale (6.2.2. NTC 2018) nonché relativa alla verifica delle opere di fondazione (6.4.NTC 2018)

ANALISI PERICOLOSITÀ SISMICA LOCALE

Relativa alla caratterizzazione geofisica del volume significativo di terreno (3.2.2 NTC 2018), valutazione dell'azione sismica di riferimento (3.2.3. NTC 2018), Risposta sismica locale e verifica della stabilità nei confronti della liquefazione (7.11.3. NTC 2018)

OGGETTO

Integrazione alla caratterizzazione geologica, geotecnica e sismica inerente all'ampliamento del nuovo impianto biometano presso l'impianto di compostaggio AIMAG, nella località Fossoli del Comune di Carpi (MO).

Proprietà: AIMAG S.p.A.

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TAVOLE

Tav. n. 1: “Carta Topografica”

scala 1: 5.000

Tav. n. 2: “Ripresa Satellitare”

scala 1: 5.000

Tav. n. 3: “Ubicazione indagini”

scala 1: 1.500

ALLEGATI

ALL. n. 1 Prove penetrometriche statiche CPTU

ALL. n. 2 Prove di dissipazioni

ALL. n. 3 Indagini sismiche

ALL. n. 4 Verifica alla liquefazione

1 PREMESSE

Nel mese di novembre 2021 è stato eseguito il presente studio geologico, geotecnico e sismico integrativo inerente all'integrazione al progetto di realizzazione dell'ampliamento del nuovo impianto biometano presso l'impianto di compostaggio AIMAG S.p.A., nella località Fossoli del Comune di Carpi (MO).



Fig.1.1 - Ubicazione del sito in studio.

La presente relazione fa riferimento alle disposizioni normative contenute in:

- Norme Tecniche per le Costruzioni 2018 – D.M. 17/01/2018;
- DGR 630/2019 e aggiornamento DGR 476/2021.

2 INQUADRAMENTO GENERALE

2.1 Inquadramento geografico

L'area in esame è collocata in ambiente di pianura, nella località di Fossoli nel Comune di Carpi (Fig.2.1). Le coordinate specifiche dell'area sono le seguenti:

| SITO IN ESAME | |
|------------------------|-------------|
| COORDINATE GEOGRAFICHE | |
| LATITUDINE | LONGITUDINE |
| 44.846911 | 10.906306 |



Fig.2.1 – Ubicazione geografica del sito in studio.

Per un completo inquadramento geografico dell'area si rimanda dalla cartografia allegata alla presente relazione, in particolare alla "Carta topografica", alla scala 1: 5.000 (tav. n. 1) e alla "Ripresa satellitare" alla scala 1: 5.000 (tav. n. 2).

2.2 Elementi geologici e geomorfologici

Da quanto si evince dalla “Carta geologico-tecnica”, tratta dallo studio di Microzonazione sismica del Comune di Carpi, nell’area oggetto di studio affiora la seguente litologia:

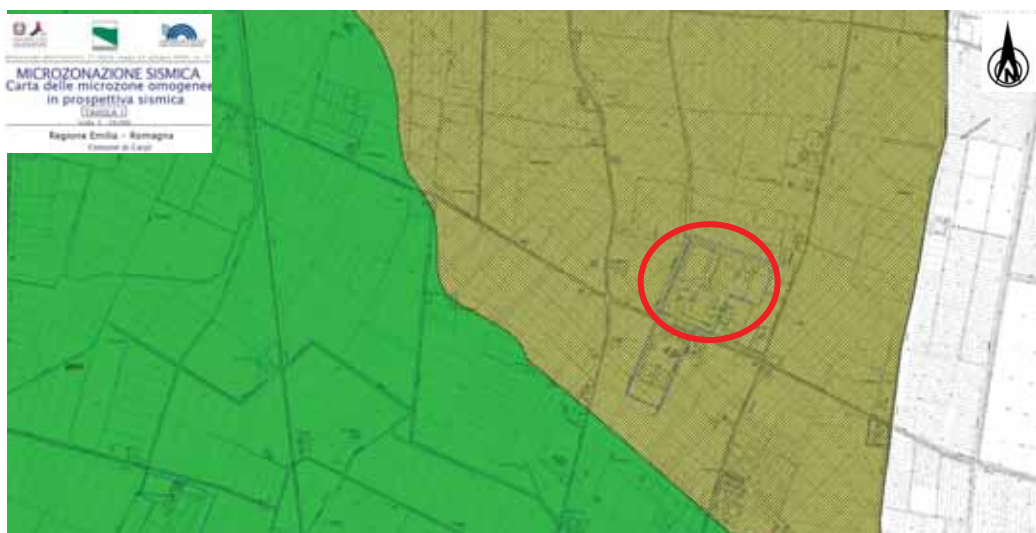
CLpa → argille inorganiche di media-bassa plasticità, argille ghiaiose o sabbie argille limose, argille magre palustri.



Fig. 2.2: Estratto della carta “Carta geologico-tecnica”.

2.3 Inquadramento sismico

A supporto dell'analisi sismica e della valutazione della stabilità del sito, successivamente descritta nei paragrafi seguenti, per quel che concerne i fenomeni co-sismici è stata preliminarmente consultata la cartografia relativa allo studio di Microzonazione Sismica del Comune di Carpi, in particolare dalla "Carta delle Microzone omogenee in Prospettiva sismica", di cui un estratto è riportato in figura (Fig. 2.3). Si nota come l'area in studio ricada in zona suscettibile di instabilità, per cui è stato svolto uno studio di terzo livello mediante risposta sismica locale.



Legenda

Zone stabili suscettibili di amplificazioni locali

- 2001 Zona 1-Alternanze di strati di argille e argille limose con strati di limi, limi sabbiosi e sabbie limose (sedimenti di provenienza appenninica)
- 2002 Zona 2-Argille e argille limose (con radi strati sabbiosi) sovrastate da un orizzonte superficiale limo-sabbioso
- 2003 Zona 3-Argille e limi prevalenti (con radi strati sabbiosi) fino ad almeno 25-40 m di profondità, sovrastanti depositi sabbiosi
- 2004 Zona 4-Peliti prevalenti (con radi strati sabbiosi) fino almeno 20-30 m di profondità
- 2005 Zona 5-Argille e limi fino 5-10 m di profondità. Sabbie prevalenti tra 5-20 m di profondità
- 2006 Zona 6-Alternanze tra strati metrici/plurimetrici sabbiosi e strati metrici/plurimetrici pelitici

Zone suscettibili di instabilità

- Liquidezioni
- Aree urbanizzate e urbanizzabili

Fig.2.3 – Carta delle microzone omogenee in prospettiva sismica.

3 INDAGINI GEOGNOSTICHE

3.1 Indagini Geotecniche

In relazione alla litologia presente nell'area e in base alla tipologia di intervento in progetto, sono state eseguite, nelle date 28/10/21 e 29/10/21, le seguenti indagini geognostiche:

- ***n. 6 prove penetrometriche statiche con punta elettrica e piezocono CPTU***

I risultati delle indagini sono riportati nell'allegato n. 1.

3.1.1 Prove penetrometriche statiche CPTU

Il penetrometro utilizzato per realizzare le prove statiche è un Gouda da 200 kN di spinta, montato su autocarro gommato a trazione integrale.

La prova penetrometrica statica con punta elettrica (CPTE/U), consiste essenzialmente nella misura della resistenza alla penetrazione di una punta conica standard, connessa all'estremità inferiore di una batteria di aste cave, che viene infissa a pressione e velocità costante nel terreno tramite un dispositivo di spinta idraulico che agisce alla sommità delle aste.



Fig. 3.1 – Attrezzatura di prova utilizzata.

La punta elettrica è strumentata con sensori elettrici e un sistema di trasmissione dei dati in superficie via cavo, che permette l'acquisizione e la registrazione dei dati quasi in continuo, ogni centimetro. I dati misurati durante la prova sono la resistenza totale alla penetrazione Q_t , la resistenza alla penetrazione della punta Q_c e la resistenza laterale del manicotto F_s ; è possibile inoltre monitorare, durante l'esecuzione della prova, alcuni parametri di controllo quali l'inclinazione rispetto alla verticalità e la velocità di penetrazione del cono. Una punta elettrica particolare, detta "piezocono", è dotata anche di un dispositivo di misura della pressione, attraverso il quale viene misurata la pressione dell'acqua nei pori del terreno u (CPTU). La pressione che viene misurata è la pressione $u = u_0 + \Delta u$, dove u_0 è la pressione dovuta al livello idrostatico e Δu quella generata dallo sforzo alla penetrazione nel terreno.

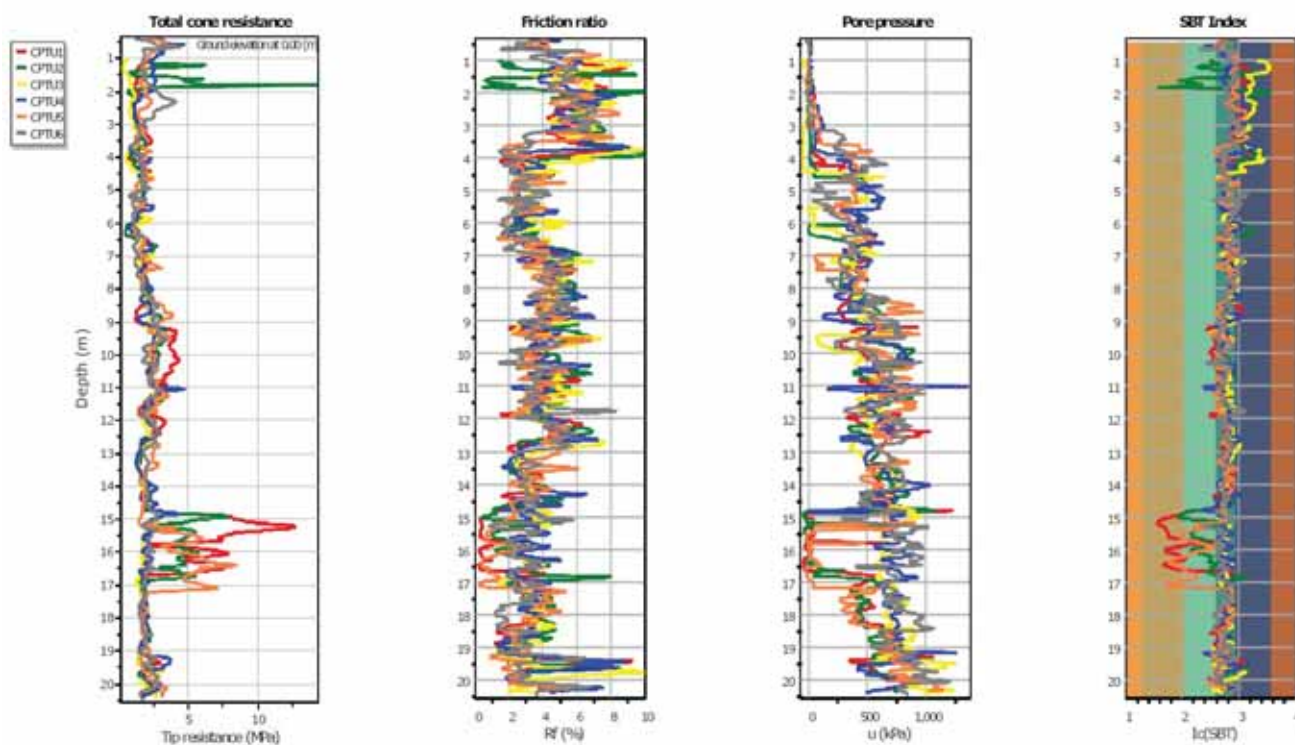
Il piezocono da Noi utilizzato è un Pagani, con sistema di acquisizione TGAS07 ed è dotato di un dispositivo di misura della pressione costituito da un cilindro metallico saturato con grasso, situato poco al di sopra della punta conica.

I dati acquisiti sono stati elaborati con software CPeT – IT v. 1.7.4.13 prodotto da GeoLogisMiki – Geotechnical Software.

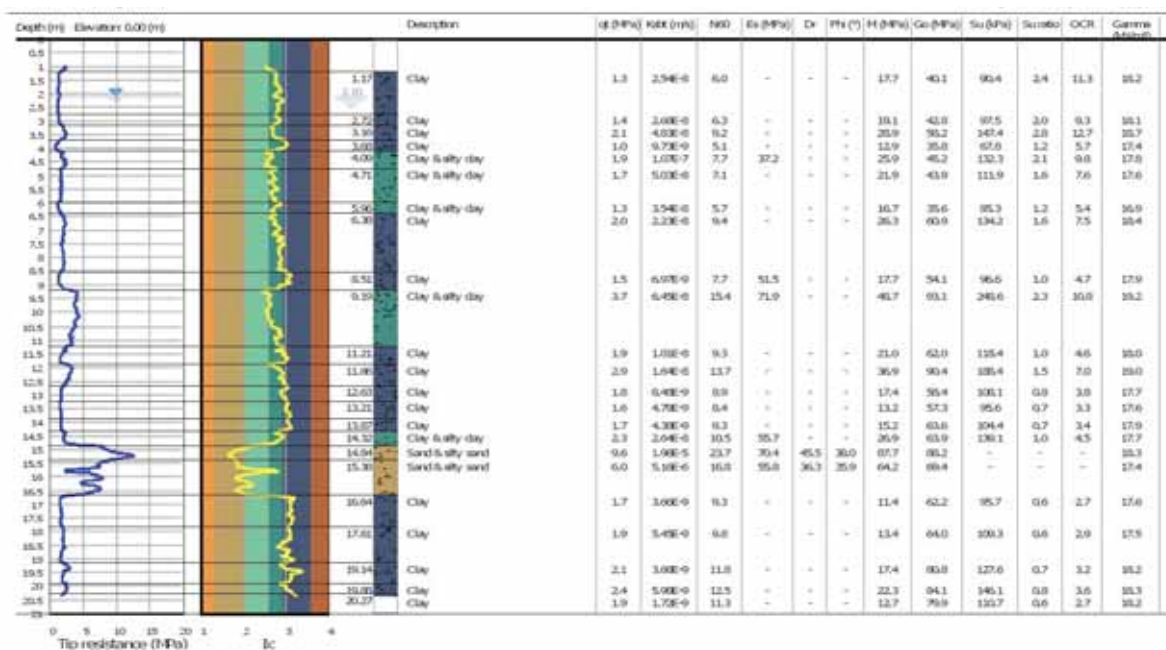
Di seguito si riportano le profondità di prova raggiunta e la soggiacenza della falda freatica.

| VERTICALI DI PROVA | PROFONDITÀ RAGGIUNTA | FALDA FREATICA |
|--------------------|----------------------|-----------------|
| CPTU 1 | -20.33 m da p.c. | -2.10 m da p.c. |
| CPTU 2 | -20.37 m da p.c. | -2.10 m da p.c. |
| CPTU 3 | -20.39 m da p.c. | -2.10 m da p.c. |
| CPTU 4 | -20.39 m da p.c. | -2.10 m da p.c. |
| CPTU 5 | -20.35 m da p.c. | -2.10 m da p.c. |
| CPTU 6 | -20.47 m da p.c. | -2.10 m da p.c. |

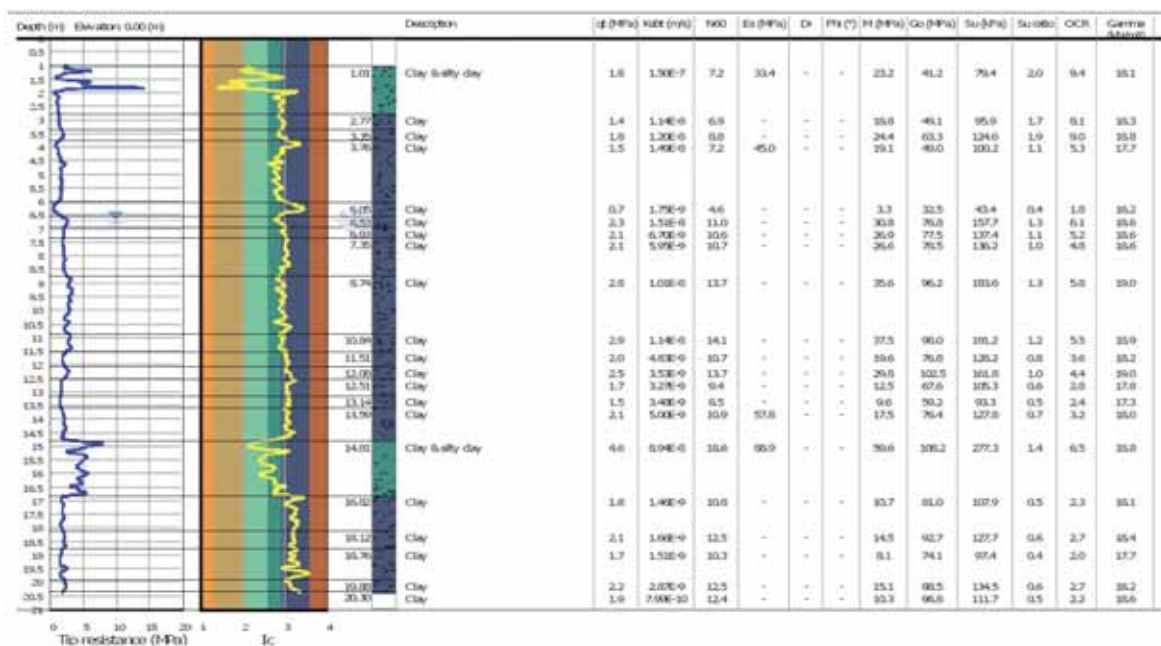
Overlay basic interpretation plots



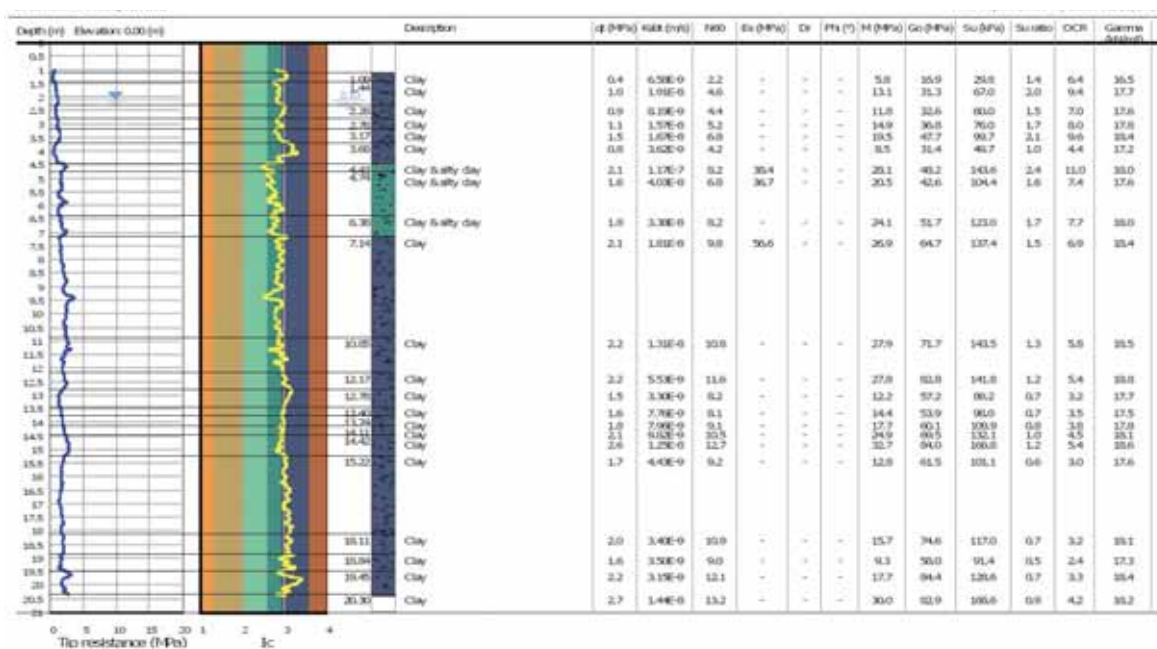
CPTU 1



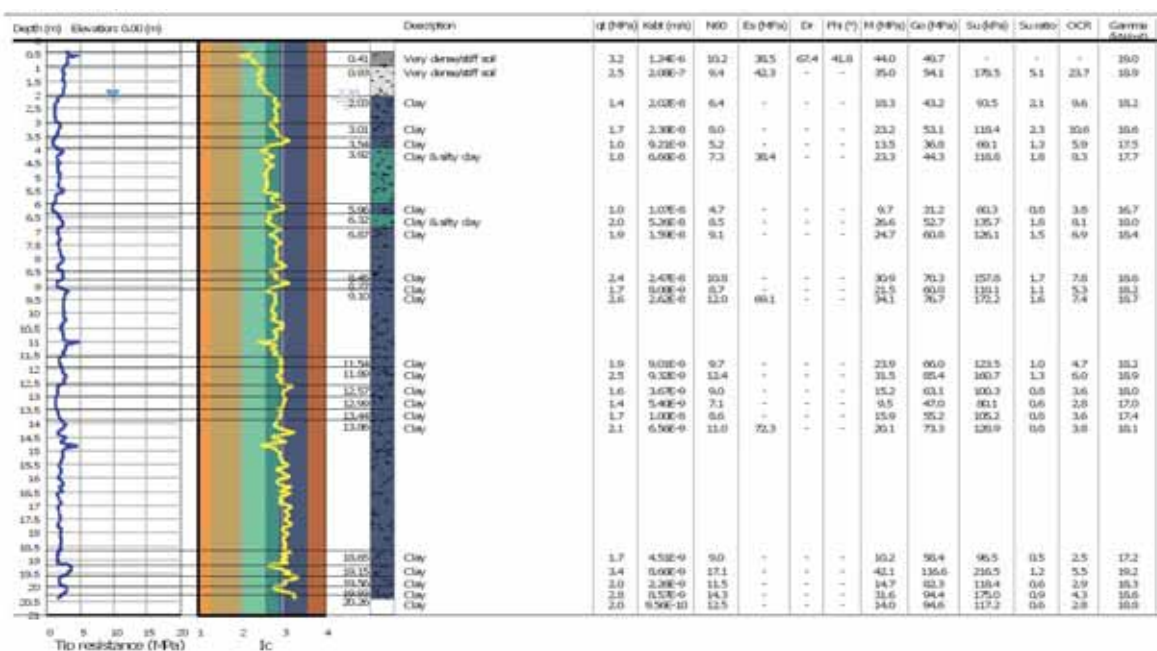
CPTU 2



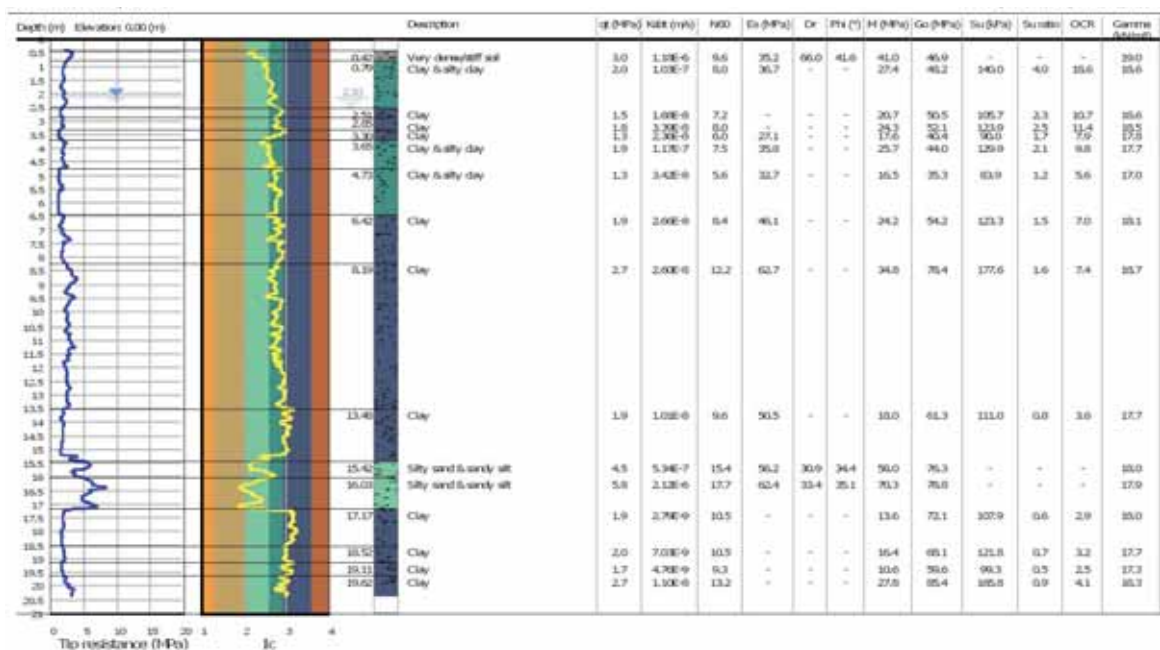
CPTU 3



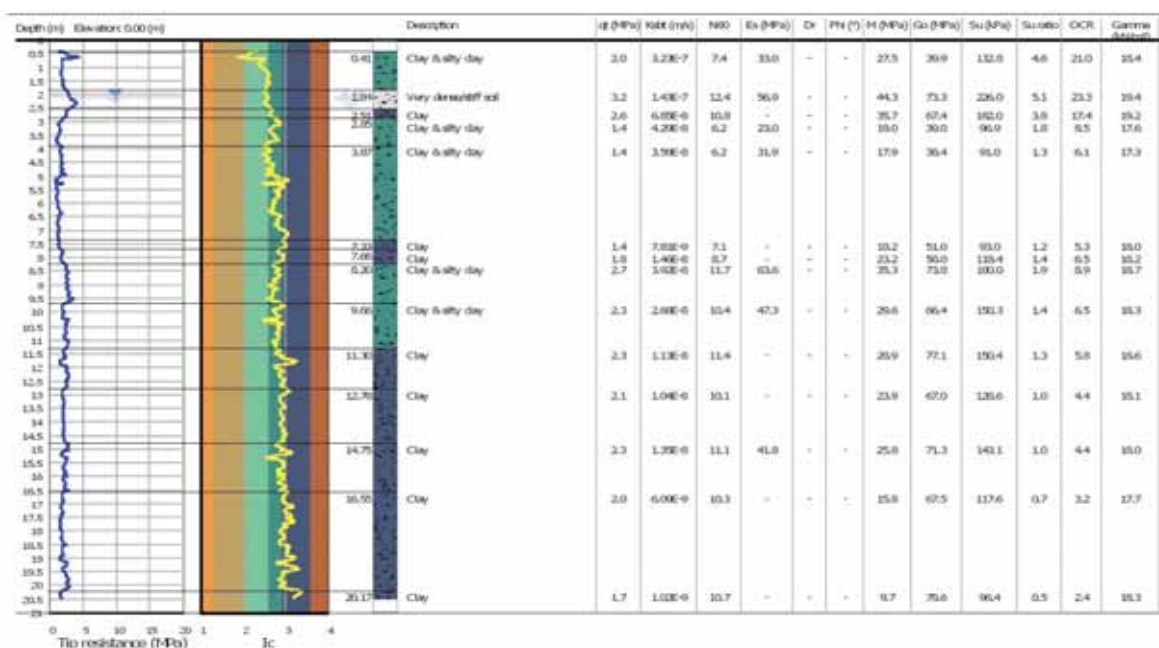
CPTU 4



CPTU 5



CPTU 6



Inoltre, durante l'esecuzione della prova penetrometrica CPTU è possibile effettuare prove di dissipazione della pressione neutra.

In sito sono state eseguite in totale n. 4 dissipazioni totali lungo le verticali di prova alle profondità riportate in tabella:

| CPTU | DISSIPAZIONE | PROFONDITÀ (m da p.c.) |
|--------|--------------|------------------------|
| CPTU 3 | 1 | -6.00 |
| CPTU 4 | 1 | -4.01 |
| CPTU 5 | 1 | -10.01 |
| CPTU 6 | 1 | -15.00 |

Tab. 3.2 – Quota delle prove di dissipazione.

La prova di dissipazione viene eseguita mediante la sospensione dell'avanzamento di una prova penetrometrica statica di tipo CPTU. Questa prova consiste nel misurare il tempo ed il modo di dissipazione della pressione interstiziale che è venuta a crearsi durante l'avanzamento della punta.

I risultati ottenuti sono riportati nelle tabelle sottostanti mentre i grafici sono riportati nell'apposito allegato.

| CPTU Borehole | Depth (m) | $(t_{50})^{0.50}$ | t_{50} (s) | t_{50} (years) | G/S_u | C_h (m^2/s) | C_h ($m^2/year$) | M (MPa) | k_h (m/s) |
|---------------|-----------|-------------------|--------------|------------------|---------|-------------------|----------------------|---------|-------------|
| CPTU3 | 6.00 | 3.0 | 9 | 2.82E-007 | 444.29 | 1.94E-004 | 6128 | 22.81 | 8.36E-008 |

| CPTU Borehole | Depth (m) | $(t_{50})^{0.50}$ | t_{50} (s) | t_{50} (years) | G/S_u | C_h (m^2/s) | C_h ($m^2/year$) | M (MPa) | k_h (m/s) |
|---------------|-----------|-------------------|--------------|------------------|---------|-------------------|----------------------|---------|-------------|
| CPTU4 | 4.01 | 8.9 | 80 | 2.52E-006 | 321.53 | 1.85E-005 | 583 | 25.66 | 7.06E-009 |

| CPTU Borehole | Depth (m) | $(t_{50})^{0.50}$ | t_{50} (s) | t_{50} (years) | G/S_u | C_h (m^2/s) | C_h ($m^2/year$) | M (MPa) | k_h (m/s) |
|---------------|-----------|-------------------|--------------|------------------|---------|-------------------|----------------------|---------|-------------|
| CPTU5 | 10.01 | 24.2 | 584 | 1.85E-005 | 395.64 | 2.79E-006 | 88 | 30.95 | 8.85E-010 |

| CPTU Borehole | Depth (m) | $(t_{50})^{0.50}$ | t_{50} (s) | t_{50} (years) | G/S_u | C_h (m^2/s) | C_h ($m^2/year$) | M (MPa) | k_h (m/s) |
|---------------|-----------|-------------------|--------------|------------------|---------|-------------------|----------------------|---------|-------------|
| CPTU6 | 15.00 | 18.6 | 348 | 1.10E-005 | 513.13 | 5.35E-006 | 169 | 33.31 | 1.57E-009 |

3.2 Indagini Geofisiche

Per la caratterizzazione sismica dell'area di studio, in data 04/09/19, sono state eseguite le seguenti indagini geofisiche:

- *n. 1 indagine sismica HVSR*
- *n. 1 indagine sismica MASW*

I risultati sono riportati integralmente nell'allegato n. 2.

3.2.1 Indagine sismica passiva a stazione singola (analisi HVSR)

La misura sismica passiva a stazione singola è stata eseguita mediante un tomografo digitale dotato di tre canali velocimetrici, modello Tromino® prodotto da Moho srl [Marghera (VE), Italia]. Per l'acquisizione è stata adottata una frequenza di campionamento di 128 Hz per una durata totale di 20 minuti (Fig.3.1).

Lo scopo dell'indagine è la misura della frequenza di risonanza del terreno, la quale è legata alla velocità delle onde di taglio V_s nel terreno dalla formula:

$$f = \frac{V_s}{4h}$$

dove h è lo spessore dello strato.

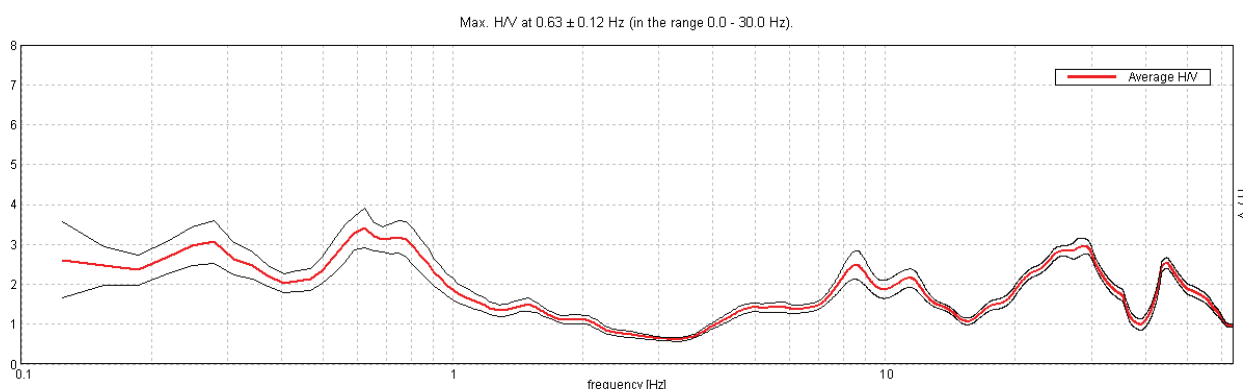


Fig.3.2 - Curva HVSR che identifica un picco a 0.63 Hz.

3.2.2 Indagine sismica attiva con metodo MASW

Per misurare le velocità delle onde di taglio si possono eseguire prospezioni sismiche mediante stendimenti superficiali, utilizzando geofoni verticali da 4,5 Hz ed acquisendo attivamente i segnali delle onde rifratte alla superficie mediante una sorgente artificialmente provocata. Questa tecnica, nota con la sigla **MASW** (Multichannel Analysis of Surface Waves), permette di ricostruire il profilo verticale delle Vs con procedimenti di modellazione diretta delle velocità di fase delle onde, rifratte alla superficie. Partendo dal sismogramma registrato mediante sorgente energizzante in asse con lo stendimento, viene eseguita un'analisi spettrale che ha consentito di elaborare un'immagine della distribuzione del segnale di velocità sismica in funzione delle diverse frequenze che lo compongono. Da tale elaborazione, tramite una fase di "picking" del segnale ad elevata intensità è stata ottenuta la **"curva di dispersione"**, dalla cui inversione è stato calcolato il **modello sismo-stratigrafico** espresso in termini di velocità delle onde di taglio (Vs) (Fig. 3.5). I dati sono stati registrati mediante un sismografo *Geode Geometrics* 24 bit con filtri disinseriti, velocità di campionamento (sample rate) di 0.25 millisecondi e lunghezza delle acquisizioni di 2 secondi. Si effettuano battute poste ad offset diversi (10 m e 15 m di distanza dal primo geofono) mediante grave da 8,0 kg di massa. Il calcolo del profilo delle velocità delle onde di Rayleigh, $V(\text{fase})/\text{freq.}$, può essere convertito nel profilo Vs/profondità. Tale metodo non è univoco e quindi il modello che ne scaturisce è un modello teorico; per questo motivo è preferibile operare in presenza di dati di taratura (come nel caso specifico) onde ricavare il modello reale.

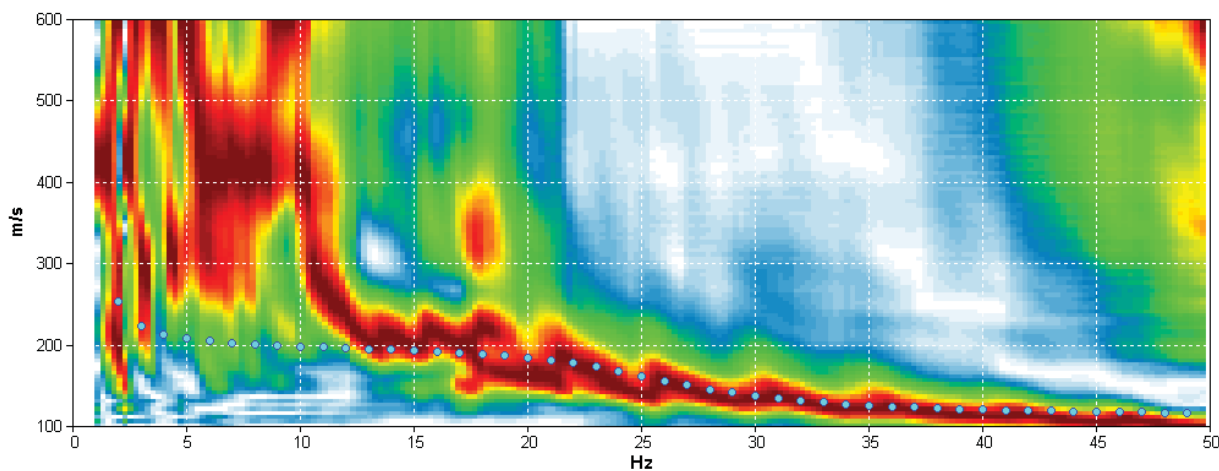


Fig.3.3 - Curva di dispersione MASW.

4 CARATTERIZZAZIONE SISMICA DEL SITO

4.1 Pericolosità sismica di base

Secondo la classificazione sismica del territorio nazionale proposta a partire dall'O.P.C.M. n. 3274/2003 e successive modifiche, il **Comune di Carpi (MO)** risulta appartenente alla **classe di sismicità 3** (Fig. 4.1).

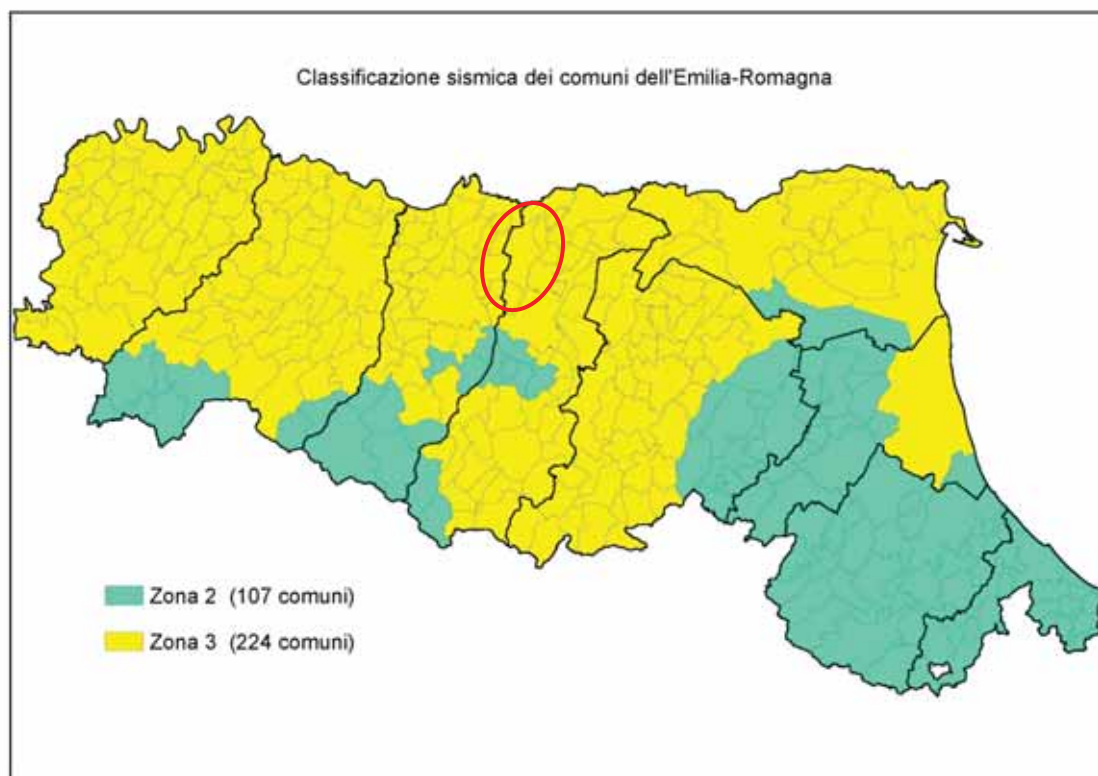


Fig.4.1 - Classificazione sismica dei comuni della Regione Emilia-Romagna (DGR 1164/18).

La suddivisione del territorio nazionale in zone a diversa classe di sismicità, caratterizzate da un valore di accelerazione di picco ed un corrispondente spettro di risposta elastico da utilizzare nella progettazione, risulta in realtà superata dall'entrata in vigore del D.M. 14/01/2008. Sulla base dei contenuti delle NNTC 2008 e delle successive NTC 2018, per ogni costruzione deve essere definita un'accelerazione di riferimento propria, in funzione delle coordinate geografiche dell'area e della vita nominale dell'opera.

Per ciascuna area in oggetto, in relazione a un periodo di riferimento T_R stimato di 475 anni, è stato definito un parametro di accelerazione massima attesa a_g definita in condizioni di campo libero su sito di riferimento rigido e con superficie topografica orizzontale. L'accelerazione a_g rappresenta uno dei parametri principali che definisce la **pericolosità sismica di base**, insieme ai parametri F_0 e T_c^* dello spettro di risposta elastico, desumibili nelle tabelle riportate sotto (Tab. 4.1).

Stati limite

Classe Edificio

II. Affollamento normale: Assenza di funz. pubbliche e sociali

Vita Normale 50

Interpolazione Media ponderata

CU = 1

| Stato Limite | T_r [anni] | A_g [g] | F_0 | T_c [s] |
|--|--------------|-----------|-------|-----------|
| Operatività (SLO) | 30 | 0.040 | 2.561 | 0.247 |
| Danno (SLD) | 50 | 0.050 | 2.519 | 0.265 |
| Salvaguardia vita (SLV) | 475 | 0.149 | 2.582 | 0.269 |
| Prevenzione collasso (SLC) | 975 | 0.200 | 2.530 | 0.276 |
| Periodo di riferimento per fazione sismica: | 50 | | | |

Coefficienti sismici

Tipo Stabilità dei pendii e fondazioni

☐ Muri di sostegno che non sono in grado di subire spostamenti

H [m] 1 H [m] 0.1

Cal. Sottosuolo C

Cal. Topografica Tt

| | SLO | SLD | SLV | SLC |
|---------------------------------|------|------|------|------|
| SS Amplificazione stratigrafica | 1.50 | 1.50 | 1.47 | 1.40 |
| CC Coeff. funz. categoria | 1.66 | 1.63 | 1.62 | 1.61 |
| ST Amplificazione topografica | 1.00 | 1.00 | 1.00 | 1.00 |

☐ Acc. ne massima attesa al sito [m/s²] 0.0

| Coefficienti | SLO | SLD | SLV | SLC |
|-------------------------------|-------|-------|-------|-------|
| k_h | 0.012 | 0.015 | 0.052 | 0.079 |
| k_v | 0.006 | 0.008 | 0.025 | 0.039 |
| A_{max} [m/s ²] | 0.584 | 0.728 | 2.143 | 2.751 |
| Beta | 0.200 | 0.200 | 0.240 | 0.280 |

Tab.4.1 - Tabella riassuntiva dei parametri sismici del sito in esame secondo NTC18.

4.2 Categoria di sottosuolo (§ 3.2.2 NTC2018)

Per determinare il parametro V_{30} e definire quindi la categoria di sottosuolo dell'area indagata (§ 3.2.2 NTC 2018) è stata eseguita in sito l'indagine sismica sopra descritta nel paragrafo precedente. Il valore di V_{30} si calcola attraverso la formula 3.2.1 delle NTC 2018:

$$V_{s,Eq} = \frac{H}{\sum_i \frac{h_i}{V_{si}}}$$

dove H è la profondità del substrato, definito come quella formazione costituita da roccia o terreno molto rigido, caratterizzata da V_s non inferiore a 800 m/s.

Dall'elaborazione delle indagini sismiche MASW e HVSR si è ottenuto il valore di $V_{s,30}$ e di frequenza naturale del terreno f_0 riportati nelle seguenti tabelle:

| | | |
|------|-----------|---------|
| MASW | V_{s30} | 213 m/s |
|------|-----------|---------|

| | | |
|------|--------------------|-------------------------------|
| HVSR | 0.63 ± 0.12 Hz | NON RISPETTA I CRITERI SESAME |
|------|--------------------|-------------------------------|

Pertanto, secondo la classificazione del sottosuolo imposta dal NTC 2018, si definisce il sottosuolo indagato come appartenente alla appartenente alla **categoria C**, corrispondente a:

DEPOSITI DI TERRENI A GRANA GROSSA MEDIAMENTE ADDENSATI O TERRENI A GRANA FINA MEDIAMENTE CONSISTENTI CON PROFONDITÀ DEL SUBSTRATO SUPERIORI A 30 m, CARATTERIZZATI DA UN MIGLIORAMENTO DELLE PROPRIETÀ MECCANICHE CON LA PROFONDITÀ E DA VALORI DI VELOCITÀ EQUIVALENTE COMPRESI TRA **180 m/s** E **360 m/s**.

4.3 Azione sismica e risposta sismica del sito – Approccio semplificato

Per la definizione dell'azione sismica, sulla base di quanto previsto dalle NTC si può fare riferimento ad un approccio semplificato che si basa sull'individuazione della categoria di sottosuolo e le condizioni topografiche del sito, in funzione delle quali si definiscono l'entità dell'amplificazione stratigrafica e topografica. Sulla base delle NTC 2018, e tenendo conto dei dati ottenuti dalle indagini geofisiche eseguite in sito, si classifica il terreno di fondazione in oggetto, come appartenente alla **categoria C**.

Si ricava quindi il **fattore stratigrafico S_s** , mediante la seguente relazione, valida suoli in classe C:

$$1.00 \leq S_s = 1.70 - (0.60 \cdot F_o \cdot a_g/g) \leq 1.50 \quad (4.1.1)$$

dove:

- F_o = fattore che quantifica l'amplificazione spettrale massima, su sito di riferimento rigido orizzontale, ed ha valore minimo pari a 2.2;
- a_g/g = accelerazione orizzontale del sito, con tempo di ritorno pari a **475 anni**/accelerazione di gravità;
- S_s = coefficiente di amplificazione stratigrafica o fattore stratigrafico, calcolato tramite la relazione sopra riportata.

Successivamente, sulla base delle condizioni topografiche del sito studiato, si considera un valore di un fattore topografico S_T sulla base della seguente tabella:

| Categoria topografica | Ubicazione opera/intervento | S_T |
|-----------------------|---|------------|
| T1 | Superficie pianeggiante, pendii e rilievi isolati con inclinazione media $\leq 15^\circ$ | 1.0 |
| T2 | Pendii con inclinazione media $> 15^\circ$ | 1.2 |
| T3 | Rilievi con larghezza in cresta molto minore che alla base e inclinazione media $15^\circ \leq i \leq 30^\circ$ | 1.2 |
| T4 | Rilievi con larghezza in cresta molto minore che alla base e inclinazione media $> 30^\circ$ | 1.4 |

Per l'area studiata si riportano in tabella i parametri della pericolosità di base.

| PARAMETRI PERICOLOSITÀ DI BASE | | | | | |
|--------------------------------|----------|-------|------------|-------|-------|
| Tr (anni) | $a_g(g)$ | F_o | $T_c^*(s)$ | S_s | S_T |
| 475 | 0.149 | 2.582 | 0.269 | 1.47 | 1.00 |

Si calcola infine per ciascuna area l'accelerazione massima orizzontale A_{max} con la seguente formula:

$$A_{max} = S_s \cdot S_T \cdot a_g = 1.47 \cdot 1.0 \cdot 0.149 = 0.219g$$

4.4 Azione sismica e risposta sismica del sito – Analisi di risposta sismica locale

Dato che l'area in studio ricade in parte in una zona soggetta a liquefazione §2.3, si è provveduto allo studio di risposta sismica locale di terzo livello.

Per ottemperare ai riferimenti normativi citati l'analisi è stata svolta secondo quanto indicato al § 7.11.3 delle NTC 2018, attraverso analisi numerica monodimensionale in campo lineare equivalente. Per fare ciò è stato utilizzato come strumento di lavoro il software di calcolo STRATA (University of Texas - Austin).

Ai fini della restituzione degli spettri di accelerazione, relativi allo stato limite SLV, è stata svolta la verifica dell'amplificazione del sito mediante l'utilizzo di un modello simulato in campo lineare equivalente.

Utilizzando un modello lineare equivalente è possibile ottenere una soluzione di un modello non lineare, attraverso analisi lineari complete nelle quali al termine di ogni interazione vengono aggiornati i parametri di **rigidezza** e **smorzamento** che sono dipendenti dallo stato di deformazione del terreno. Attraverso un'iterazione di calcoli si raggiunge una convergenza prefissata a monte della fase di computazione.

Il software STRATA è in grado di valutare la risposta sismica di un deposito di terreno, considerando un profilo monodimensionale in cui si propagano linearmente le onde sismiche, in funzione dei parametri dinamici attribuiti al terreno. Il terreno viene schematizzato come un sistema di N strati orizzontali omogenei, isotropi e visco-elastici, sovrastanti un semispazio uniforme, attraversati da un treno di onde di taglio che incidono verticalmente le superfici. Ogni strato è descritto per mezzo dello spessore H , del modulo di taglio massimo G_{\max} o dalla corrispondente velocità massima V_{\max} , dal valore dello smorzamento D , dal peso dell'unità di volume γ e dalle curve di decadimento del modulo di rigidezza a taglio normalizzato ($G/G_0 - \gamma$) e le corrispondenti curve dello smorzamento ($D - \gamma$) con la deformazione di taglio γ . Il modello lineare visco-elastico fa riferimento al modello reologico di Kelvin-Voigt, costituito da una molla e uno smorzatore viscoso in parallelo. Tale modello è descritto quindi dalla rigidezza (**G**) e dallo smorzamento (**D**). L'onda monodimensionale viene descritta dall'equazione in cui lo spostamento provocato (u) è funzione della profondità (z) e del tempo (t):

$$u(z,t) = A \exp[i(\omega t + k^* z)] + B \exp[i(\omega t - k^* z)]$$

Nell'equazione appena presentata A e B rappresentano le corrispettive amplificazioni del tetto e della base dello strato considerato. Il fattore k^* risulta dipendente dal modulo di taglio (G), dal grado di smorzamento (D) e dalla densità del terreno (ρ). Le relazioni sono le seguenti:

$$k^* = \frac{\omega}{v_s^*}$$

$$v_s^* = \sqrt{\frac{G^*}{\rho}}$$

$$G^* = G \left(1 - 2D^2 + i2D \sqrt{1 - D^2} \right) \approx G(1 + i2D)$$

Dove G^* e v_s^* rappresentano il modulo di taglio e la velocità di taglio.

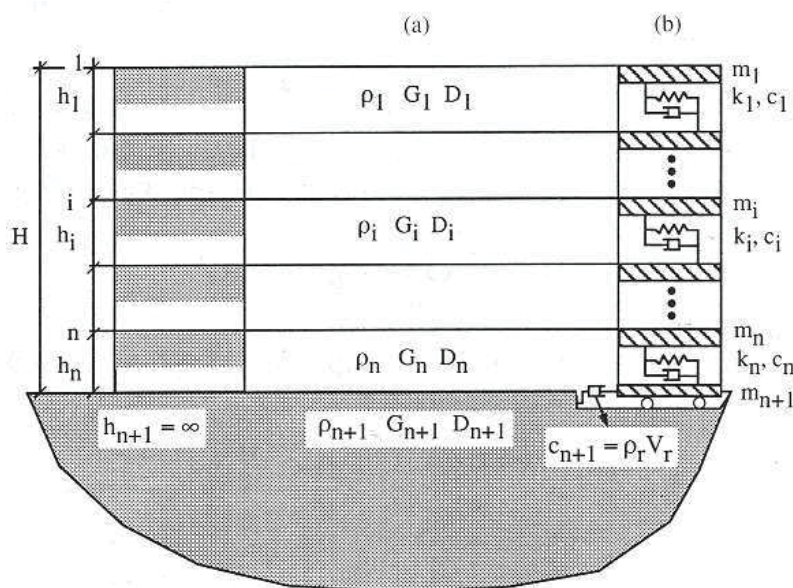


Fig.4.2 - Modello a strati continui adottato per la simulazione con il codice di calcolo STRATA.

MODELLO SIMULATO

Il modello simulato deriva dai dati ottenuti dalle prove che compongono la campagna geognostica eseguita in sito. Tale profilo approssima il comportamento del sottosuolo, dal punto di vista sismico, in corrispondenza dell'area studiata. Il profilo considerato deriva dall'interpolazione dei dati provenienti dalle indagini geofisiche eseguite, e i dati, di natura bibliografica, disponibili per il sito di riferimento.

Il profilo sismico del sottosuolo utilizzato per la modellazione della RSL deriva dall'elaborazione delle indagini sismiche eseguite in sito integrato con dati di bibliografici. Si illustra successivamente il modello utilizzato:

| Depth at the bottom of the layer [m] | Thickness [m] | Vs [m/s] | Poisson ratio |
|--------------------------------------|---------------|----------|---------------|
| 2.00 | 2.00 | 120 | 0.42 |
| 22.00 | 20.00 | 220 | 0.42 |
| 51.00 | 29.00 | 240 | 0.42 |
| 89.00 | 38.00 | 300 | 0.42 |
| 144.00 | 55.00 | 450 | 0.42 |
| inf. | inf. | 600 | 0.42 |

EXPERIMENTAL vs. SYNTHETIC H/V

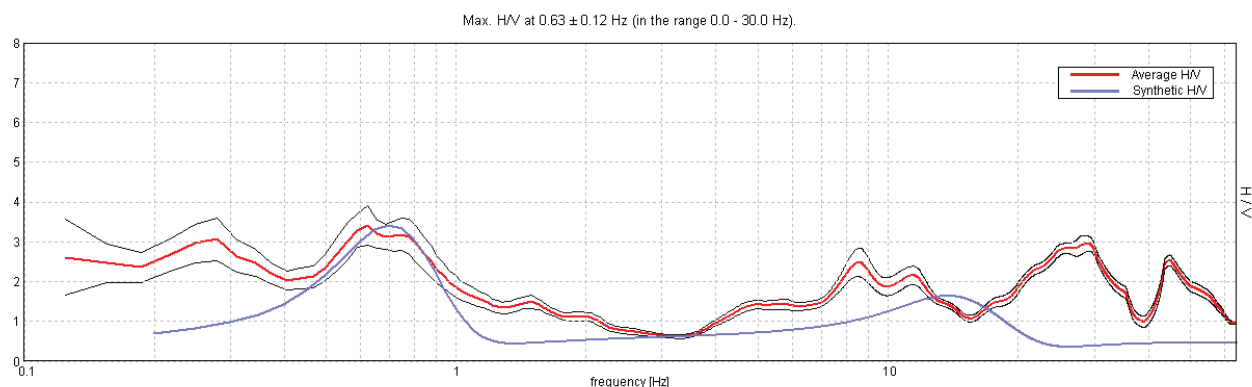


Fig.4.3 – Elaborazione HVSR.

Per descrivere il comportamento dinamico dei terreni costituenti il modello sono state considerate curve di decadimento dei moduli di rigidezza e smorzamento, al variare della deformazione percentuale $\gamma(\%)$. Si riportano successivamente le curve di decadimento considerate per l'esecuzione del calcolo di risposta sismica locale:

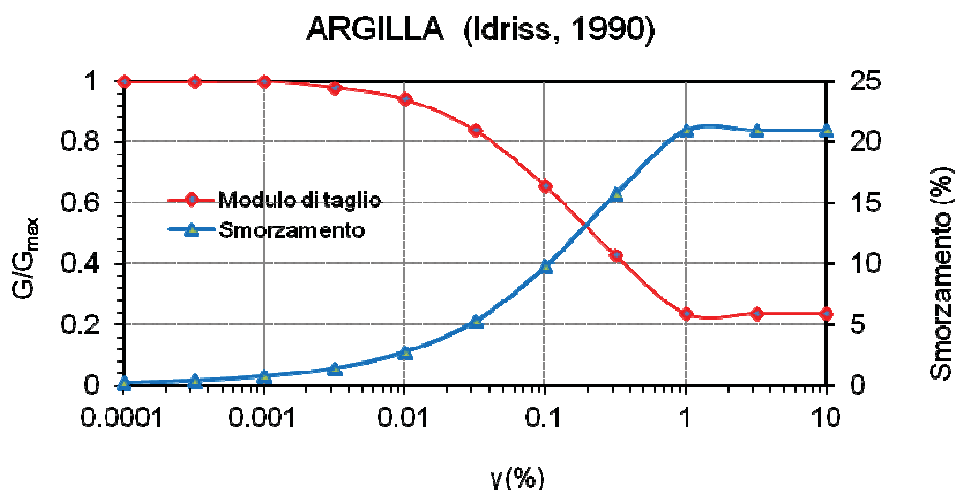


Fig.4.4 - Curve di decadimento dei moduli G/G_{max} e D , utilizzate per descrivere il comportamento dei materiali coesivi che compongono il sottosuolo in oggetto.

Trattandosi di una verifica diretta ai fini progettuali, in accordo con quanto esposto nel § 7.3 delle NTC 2018, l'analisi RSL in oggetto è stata svolta adottando come input sismico 7 accelerogrammi, corrispondenti allo stato limite SLV. Gli accelerogrammi reali e misurati, sono stati individuati mediante l'utilizzo del software REXEL v. 3.5 (Computer aided code-based real record selection for seismic analysis of structures) realizzato dal Dipartimento di Strutture per l'ingegneria e l'architettura dell'Università degli Studi di Napoli Federico II. Utilizzando le coordinate relative al sito di riferimento, considerando una categoria di sottosuolo A e una classe d'uso pari a II e una vita nominale pari a 50 anni, sono stati definiti n. 7 accelerogrammi per lo stato limite SLV. Gli accelerogrammi sono stati prelevati dal "European Strong-motion Database".

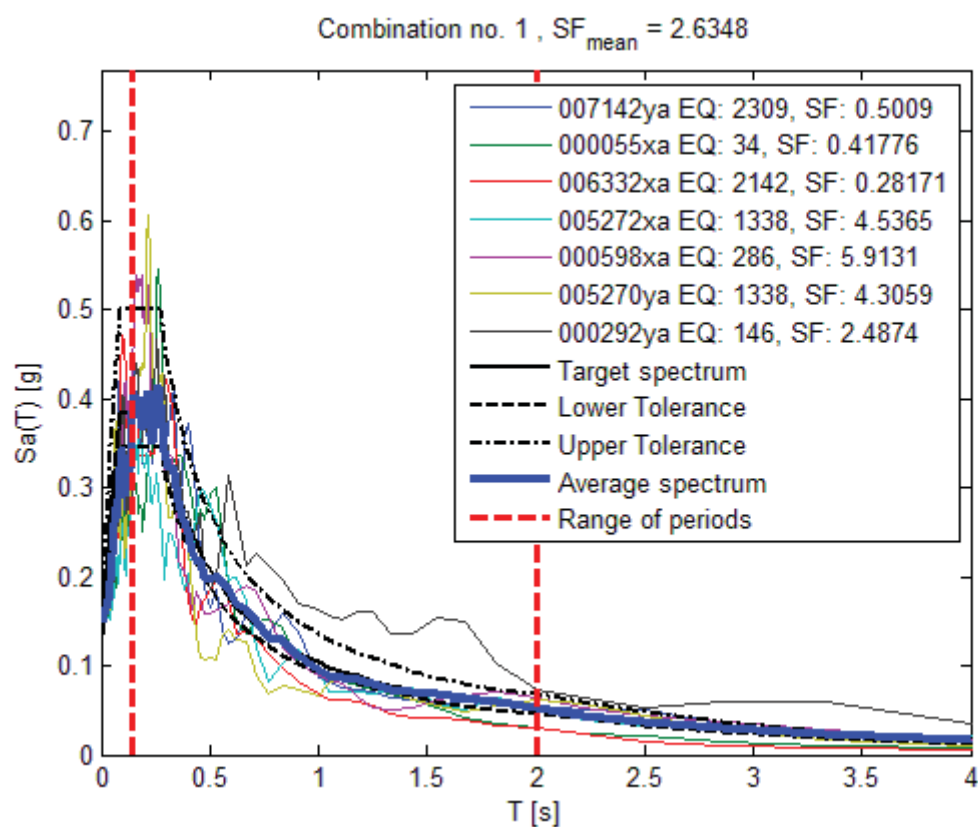
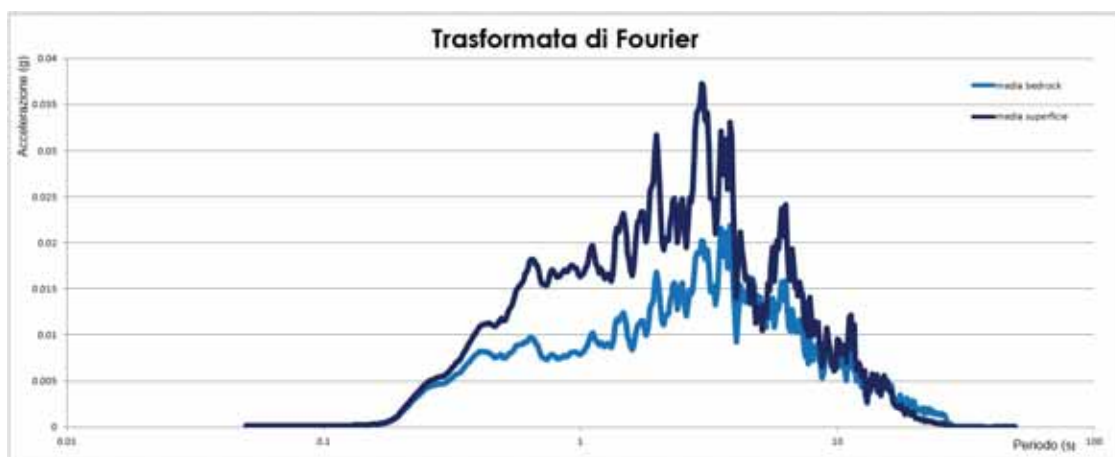
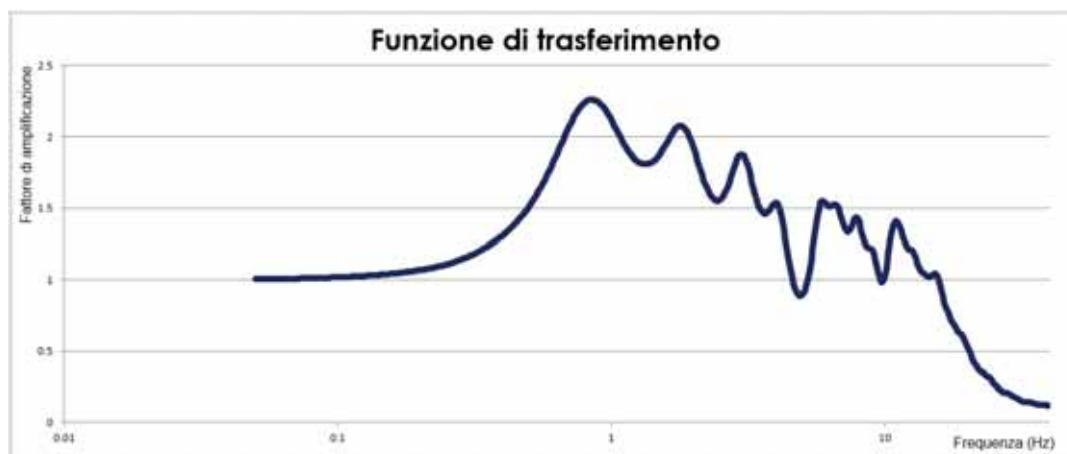


Fig.4.5 - Forme spettrali relative agli accelerogrammi considerati

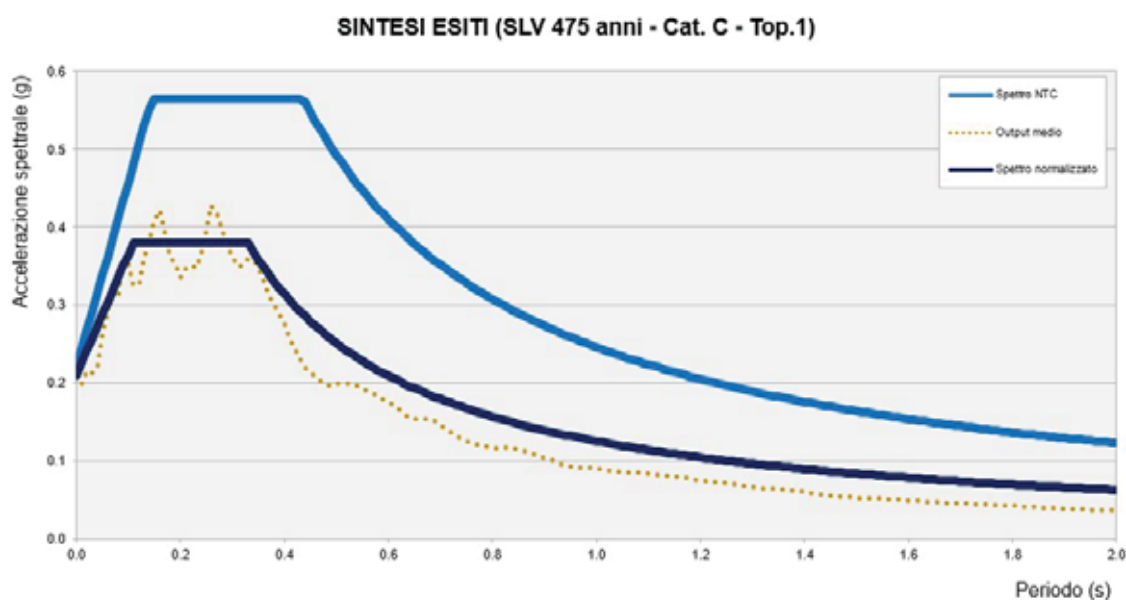
RISULTATI OTTENUTI

Sulla scorta delle verifiche svolte mediante software STRATA, in riferimento al modello considerato, è stato possibile definire, nel dominio delle frequenze, la funzione TF (Funzione di trasferimento) e rapporto spettrale di amplificazione associato. Per via grafica si inserisce successivamente la funzione di trasferimento TF ottenuta a seguito dell'analisi RSL in oggetto. Attraverso tale funzione è possibile definire il campo di frequenze entro il quale il sottosuolo, in corrispondenza del sito in oggetto, amplifica il segnale sismico, oltre che a quantificare l'amplificazione stessa.



In alto Funzione di Trasferimento e in basso funzione FT.

Dati i valori di accelerazione ottenuti dal calcolo eseguito, è stato definito lo spettro normalizzato per lo stato limite considerato. Così facendo è stato ottenuto lo spettro a probabilità uniforme, sulla base dei risultati ottenuti mediante il software STRATA. Lo spettro normalizzato RSL è stato derivato attraverso le indicazioni contenute nell'ordinanza n. 55 del 24 aprile 2018 "Disciplina per la delocalizzazione temporanea delle attività economiche o produttive e dei servizi pubblici danneggiati dal sisma eseguiti e conclusi in data anteriore a quella di entrata in vigore del decreto legge n. 189 del 2016".



Sintesi esiti RSL e confronto con spettro NTC2018 (SLV) derivato secondo l'approccio semplificato.

Lo spettro RSL, sia nella forma per punti, sia nella forma normalizzata, definito sulla base di 7 simulazioni definisce un'azione sismica inferiore rispetto a quanto derivabile secondo approccio semplificato NTC2018 per una categoria di sottosuolo di tipo C. In forza di ciò **risulta ragionevole e cautelativo adottare, ai fini di progettazione, l'azione sismica derivabile secondo approccio semplificato (categorie di sottosuolo) come esplicitato da normativa tecnica NTC 2018**. Si illustra successivamente, in forma tabellare, lo spettro RSL per punti e il suo corrispettivo normalizzato.

| SLV – PARAMETRI SPETTRO NORMALIZZATO - RSL | | | | | | |
|--|-------|-------|-------|-------|------|--------------|
| ag (g) | Fo | Tc* | TB(s) | TC(s) | Ss | Amax (g) |
| 0.149 | 1.812 | 0.269 | 0.11 | 0.33 | 1.41 | 0.210 |

5 MODELLAZIONE GEOLOGICA E GEOTECNICA DEL SITO

5.1 Modello geotecnico del sottosuolo

Sulla base dei dati emersi dall'elaborazione geotecnica e litostratigrafica delle indagini geotecniche, si può riassumere il seguente modello geotecnico schematico del terreno investigato.

| Modello geotecnico medio | | | | | | | | | | |
|--------------------------|------------|--|---|----------------------|----------------------|------------------|------------------------------------|----------------------|----------------------|-------------|
| | Profondità | Deposito | $\gamma_{\text{NAT}} / \gamma_{\text{SAT}}$ | c' | C_u | D_r | ϕ^I | E_s | M | D_w |
| A | 1.0 – 2.7 | Argilla limosa a media consistenza | 18.0/21.0 | 6.0 | 60.0 | / | 23 | 8400 | 4500 | -2.1 |
| B | 2.7 – 9.0 | Argilla limosa a media elevata consistenza | 18.5/21.5 | 8.0 | 80.0 | / | 23 | 11200 | 6000 | |
| C | 9.0 – 21.0 | Argilla limosa consistente | 19.0/22.0 | 15.0 | 150.0 | / | 25 | 21000 | 15000 | |
| | | Descrizione litologica | Peso di volume naturale e saturo | Coesione efficace | Coesione non drenata | Densità relativa | Angolo d'attrito efficace di picco | Modulo di Young | Modulo edometrico | Soggiacenza |
| | | M da p.c. | (kN/m ³) | (kN/m ²) | (kN/m ²) | (%) | (°) | (kN/m ²) | (kN/m ²) | (m da p.c.) |

Per la realizzazione delle prove penetrometriche è stato necessario realizzare prefiori fino alla quota di -1.00 m da p.c..

5.2 Stabilità nei confronti della liquefazione (§ A2.2. DGR 476/2021)

In accordo con la normativa regionale DGR 630/19 si è proceduto alla verifica della liquefazione.

La valutazione del fenomeno della liquefazione viene svolta attraverso il calcolo del fattore di sicurezza di ciascun livello che compone il sottosuolo analizzato nei confronti del fenomeno stesso. Il fattore di sicurezza è derivato secondo la seguente formulazione:

$$F_L(z) = \frac{CRR_{M=7.5; \sigma'_{v0}=1atm}}{CSR} \cdot MSF \cdot K_\sigma$$

Dove:

CRR è rappresentato dal rapporto di resistenza ciclica

MSF rappresenta il fattore di scala della magnitudo che è funzione della magnitudo stessa, della PGA e del valore di CRR

K_σ è il fattore di correzione che tiene conto della pressione efficace alla profondità a cui la resistenza viene valutata

CSR è il rapporto di tensione ciclica, ovvero la tensione di taglio indotta dall'azione sismica, normalizzata rispetto alla tensione verticale efficace. Tale parametro è derivabile secondo la seguente formulazione:

$$CSR = \frac{\tau_{media}}{\sigma'_{v0}} = 0.65 \cdot \frac{a_{maxs}}{g} \cdot \frac{\sigma_{v0}}{\sigma'_{v0}} \cdot r_d$$

I termini che compongono la seguente relazione sono rappresentati da a_{max}/g che descrive il valore dell'accelerazione orizzontale a $T = 0.00$ s, il rapporto della tensione litostatica totale ed efficace, e il coefficiente riduttivo r_d . Quest'ultimo, in accordo con la predetta normativa è stato stimato secondo la seguente formulazione:

$$r_d = \exp[\alpha(z) + \beta(z) \cdot M]$$

$$\alpha(z) = -1.012 - 1.126 \cdot \sin\left(\frac{z}{11.73} + 5.133\right)$$

$$\beta(z) = 0.106 + 0.118 \cdot \sin\left(\frac{z}{11.28} + 5.142\right)$$

dove M rappresenta il valore di magnitudo di riferimento per il sito in analisi.

Il valore **CRR** è stato ricavato attraverso la metodologia di calcolo proposta da **Boulanger&Idriss 2014**. Per le specifiche della procedura di calcolo adottata si faccia riferimento all'allegato **A2.2** della DGR 476/2021 della Regione Emilia-Romagna. L'analisi di liquefazione è stata eseguita entro i -20.00 m rispetto al piano campagna come prescritto dalla normativa di riferimento.

A seguito dell'identificazione del fattore di sicurezza F_L è stato determinato l'indice potenziale di liquefazione IL (LPI) attraverso il quale è possibile definire l'esposizione del sito al rischio di liquefazione. Il potenziale di liquefazione LPI è stato determinato secondo la seguente formulazione:

$$I_L = \int_0^{z_{crit}} F(z) \cdot w(z) \cdot dz \quad \text{in cui} \quad w(z) = \frac{200}{z_{crit}} \cdot \left(1 - \frac{z}{z_{crit}}\right)$$

Dove $F(z)$ viene determinato secondo le formulazioni proposte da Somnez (2003)

$$\begin{array}{ll} F(z) = 0 & \text{per } F_L \geq 1.2 \\ F(z) = 2 \cdot 10^6 \cdot \exp(-18.427 \cdot F_L) & \text{per } 1.2 > F_L \geq 0.95 \\ F(z) = 1 - F_L & \text{per } F_L \leq 0.95 \end{array}$$

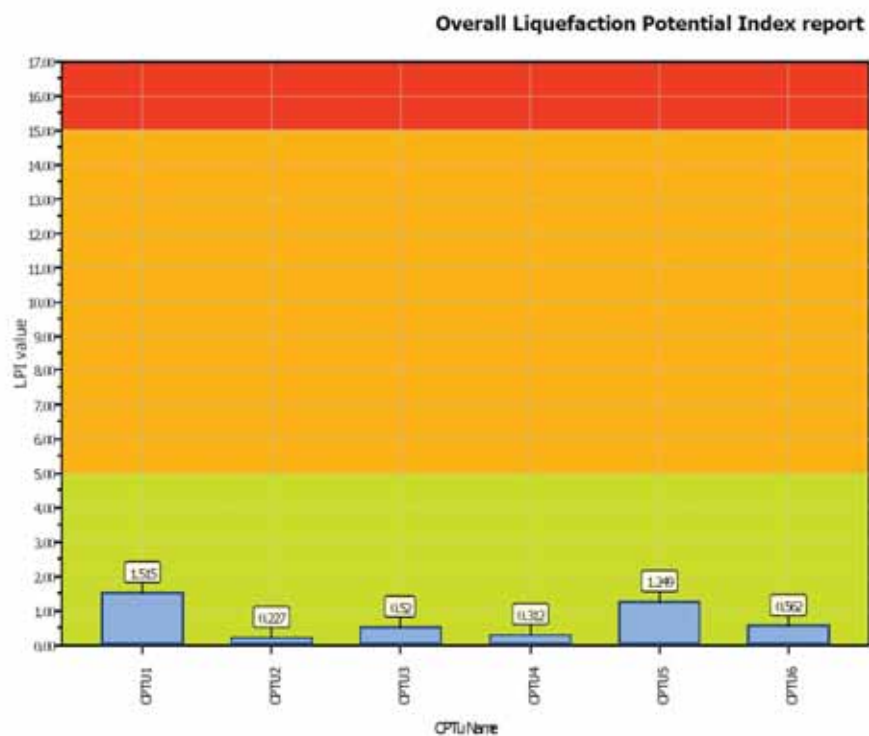
In base al valore di LPI ottenuto è possibile fornire un'indicazione del rischio di liquefazione. In considerazione delle linee guida emesse dalla Regione Emilia-Romagna, a seguito degli eventi sismici di Maggio e Giugno 2012, si considera la classificazione di rischio definita da **Somnez 2003**:

| INDICE DI LIQUEFAZIONE | Rischio di liquefazione |
|------------------------|-------------------------|
| LPI=0 | Nulla |
| 0<LPI≤2 | Basso |
| 2<LPI≤5 | Moderato |
| 5<LPI≤10 | Alto |
| 15>LPI | Molto alto |

Si illustra successivamente il valore di LPI derivato dalle verticali di prova eseguite, considerando un'accelerazione massima al suolo $A_{max} = 0.219g$ (calcolata secondo l'approccio semplificato NTC18) e una magnitudo di riferimento pari a $M = 6.14$.

A seguito della verifica, è stato ottenuto il seguente valore di LPI:

| INDAGINE | INDICE DI LIQUEFAZIONE | RISCHIO |
|----------|------------------------|---------|
| CPTU 1 | 1.515 | BASSO |
| CPTU 2 | 0.227 | BASSO |
| CPTU 3 | 0.520 | BASSO |
| CPTU 4 | 0.312 | BASSO |
| CPTU 5 | 1.249 | BASSO |
| CPTU 6 | 0.562 | BASSO |



6 CONSIDERAZIONI CONCLUSIVE

Il presente elaborato riassume e illustra le caratteristiche geologico-stratigrafiche, geotecniche e sismiche relative al volume significativo di sottosuolo indagato a supporto dell'integrazione al progetto di ampliamento del nuovo impianto biometano presso l'impianto di compostaggio AIMAG S.p.A., nella località Fossoli del Comune di Carpi (MO).

Sulla base dei dati emersi dalle indagini geotecniche eseguite (§ 3.1), si fornisce per il terreno di fondazione indagato, il modello geotecnico medio riportato nel § 5.1 della presente relazione.

In ottemperanza della normativa tecnica nazionale (NTC 2018) e in accordo con i risultati ottenuti a seguito delle indagini geofisiche espletate per il sito in oggetto è possibile classificare il terreno di fondazione come appartenente alla **categoria C**, depositi di terreni a grana grossa mediamente addensati o a terreni a grana fina mediamente consistenti con profondità del substrato superiori a 30 m, caratterizzati da un miglioramento delle proprietà meccaniche con la profondità e da valori di velocità equivalentemente compresi tra **180 m/s** e **360 m/s**.

Per la definizione dell'azione sismica, è stato eseguito l'approfondimento di terzo livello della risposta sismica locale, che risulta minore rispetto al valore ottenuto mediante l'utilizzo dell'approccio semplificato delle NTC 2018. Dall'analisi così eseguita si sono ottenuti i seguenti risultati:

| Parametri sismici | | | | |
|-------------------|------------------------------|--------------|------|-------|
| ag | Approccio semplificato NTC18 | | RSL | |
| | FA | Amax | FA | Amax |
| 0.149 | 1.47 | 0.219 | 1.41 | 0.210 |

È stata eseguita la verifica della suscettibilità al fenomeno della liquefazione considerando una accelerazione massima al suolo $A_{max} = 0.219g$ (approccio semplificato - NTC18) e una magnitudo di riferimento pari a $M=6.14$. Dall'analisi della suscettibilità nei confronti del fenomeno della liquefazione così eseguita si è ottenuto un valore di LPI pari a rischio basso.

A disposizione per ulteriori chiarimenti, cogliamo l'occasione per porgere cordiali saluti.

Modena, 18 novembre 2021

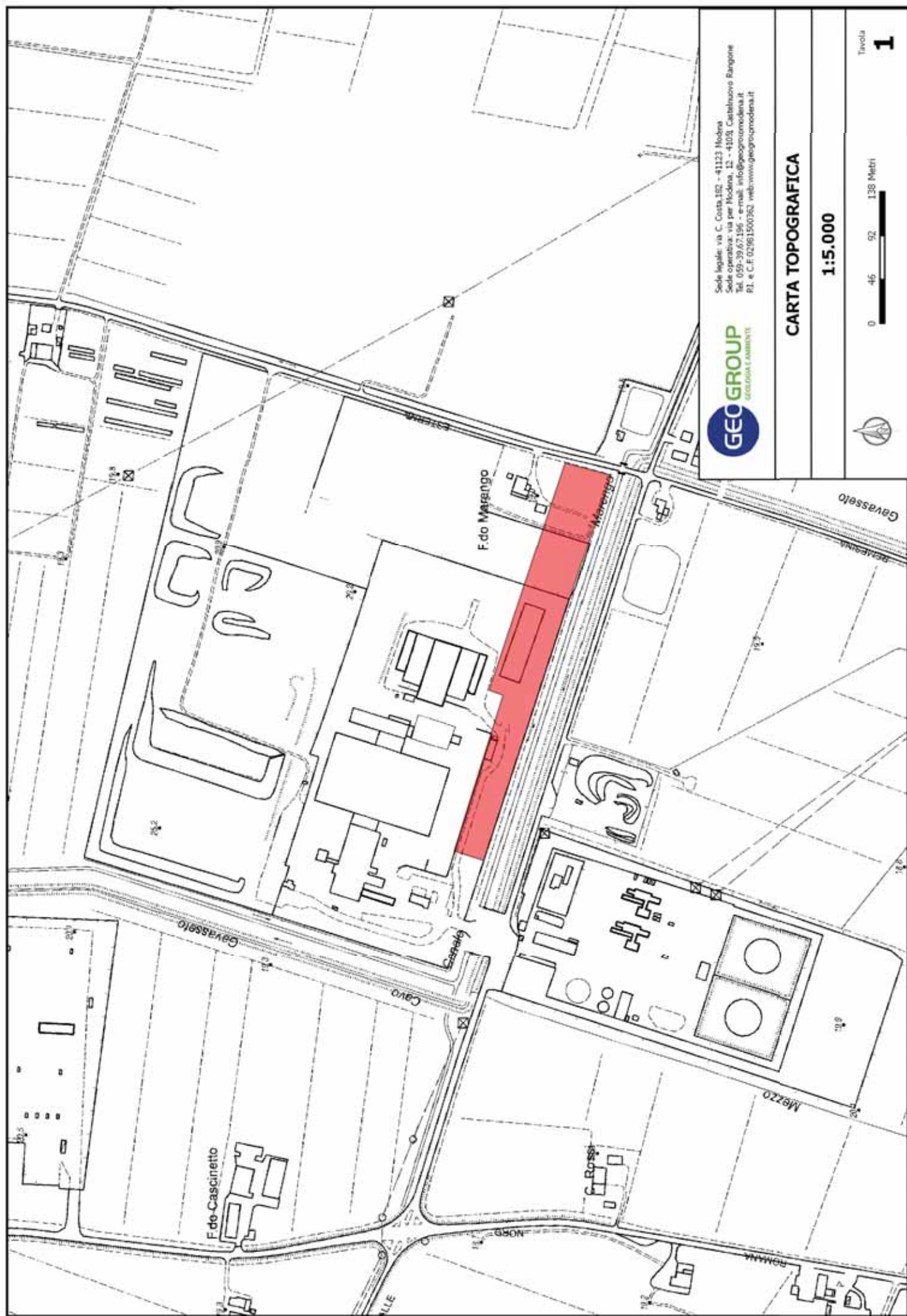
Dott. Geol. Pier Luigi Dallari



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TAVOLE



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CARTA TOPOGRAFICA

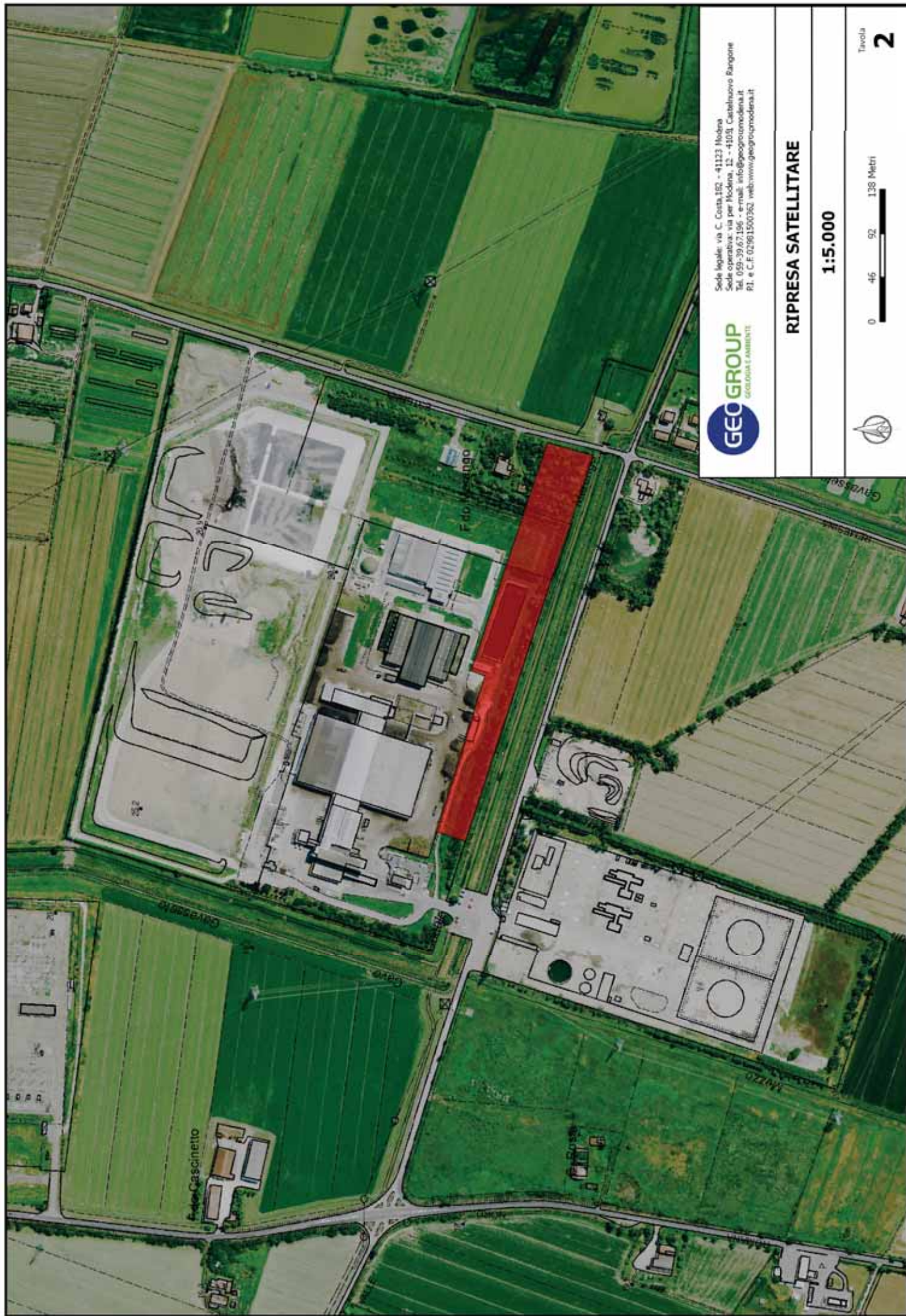
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0 46 92 138 Metri

Tavola

1



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RIPRESA SATELLITARE

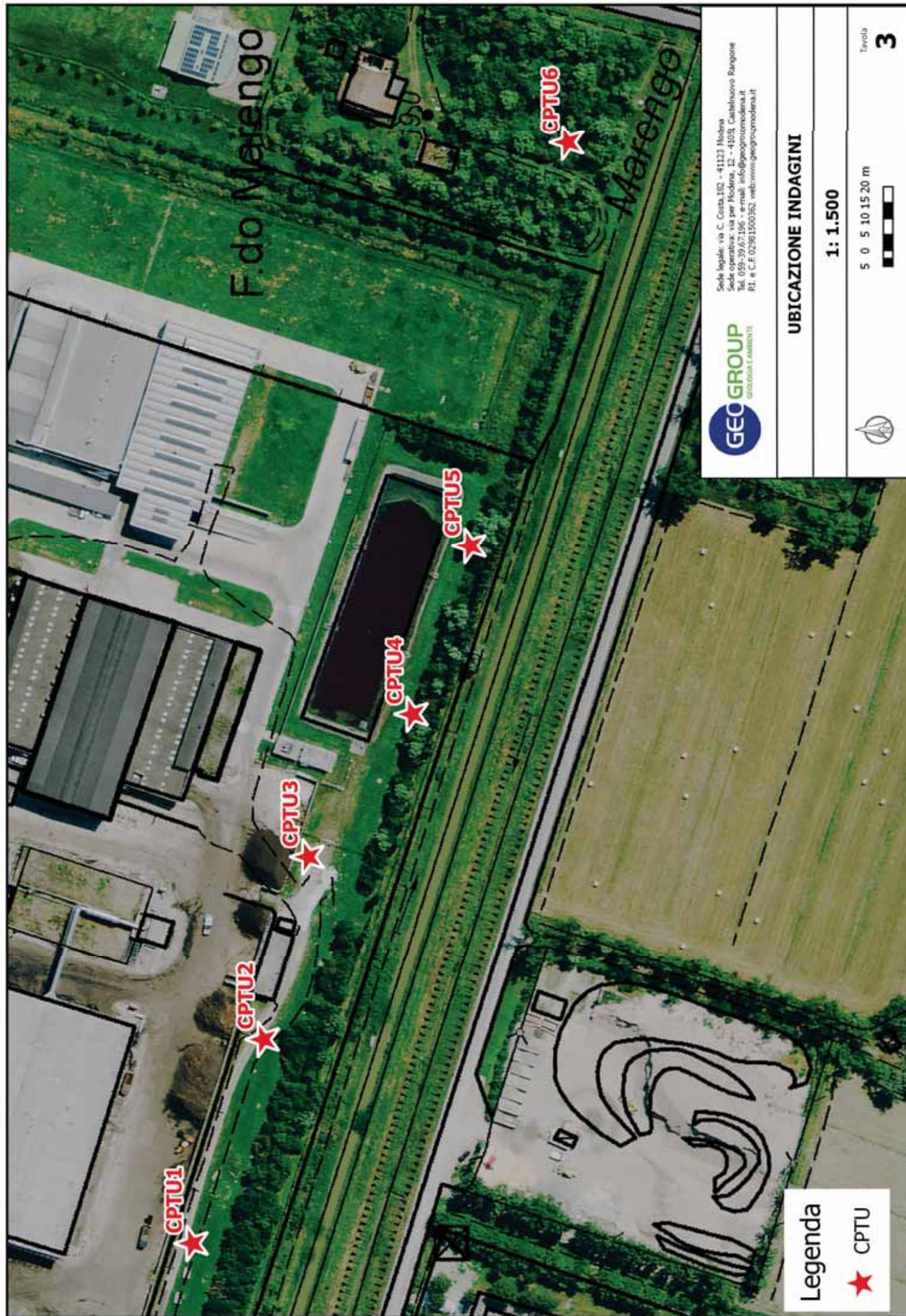
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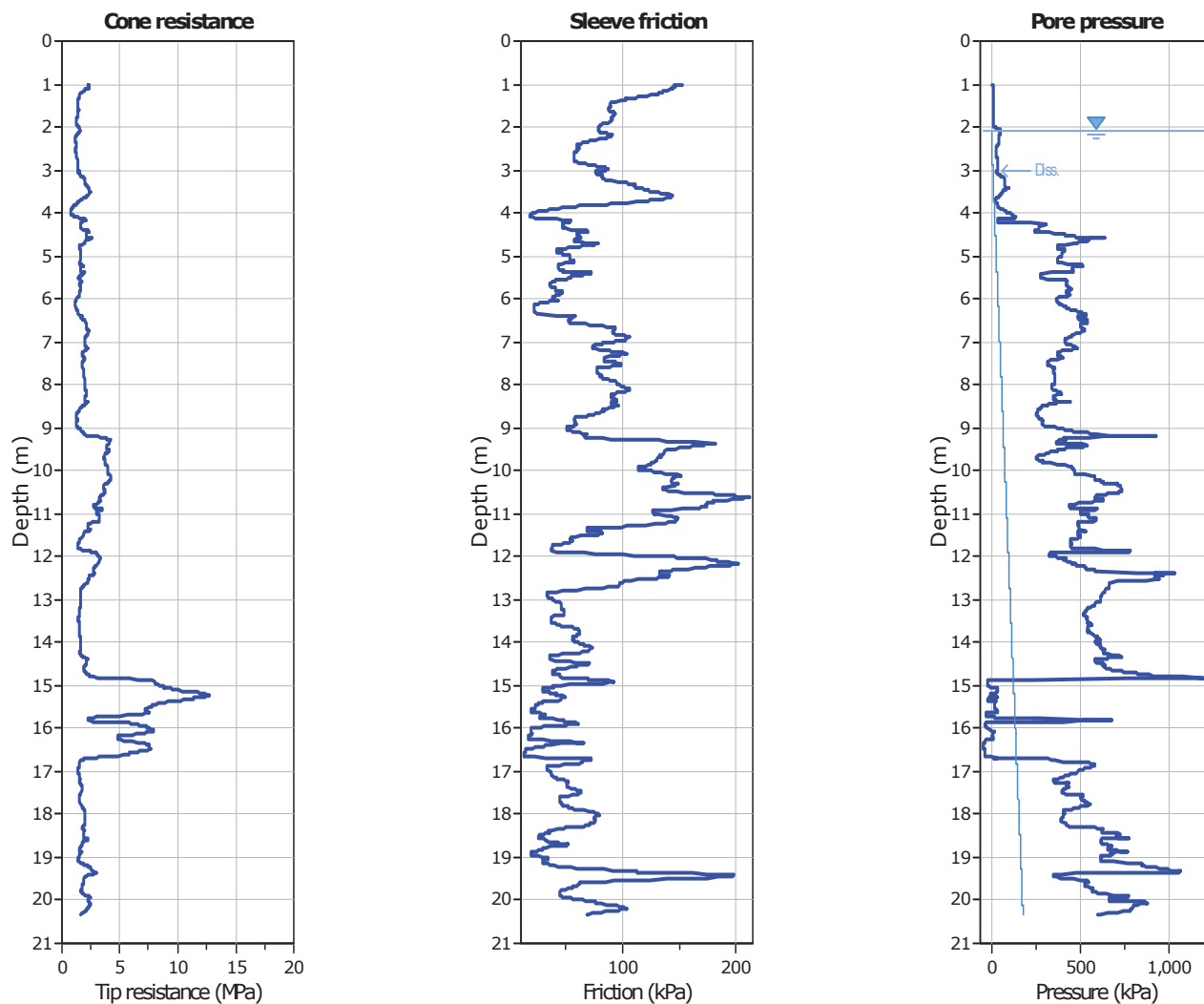


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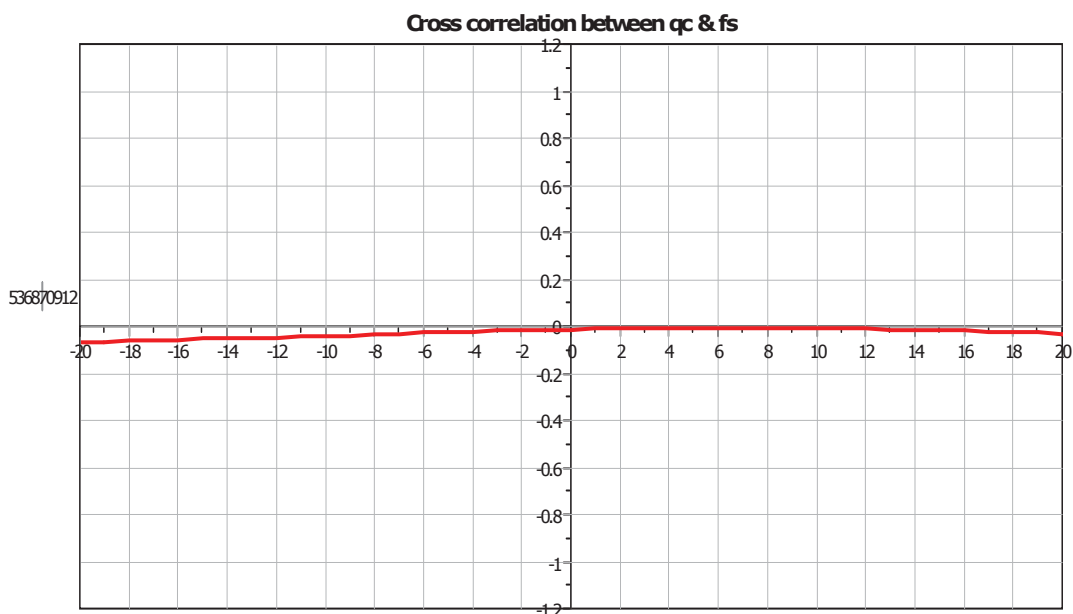
Indagini geognostiche e geofisiche – geologia applicata alle costruzioni – laboratorio geotecnico - idrogeologia
– coltivazione cave– bonifiche – consolidamenti – geologia ambientale – consulenze geologiche e geotecniche

ALLEGATO N° 1

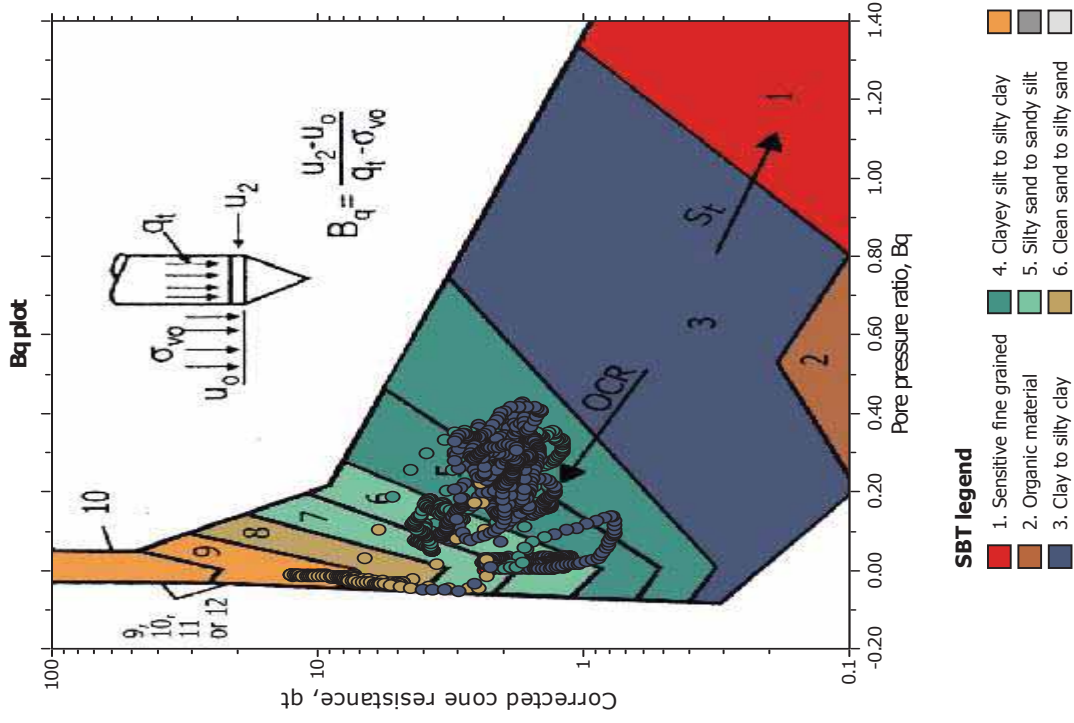
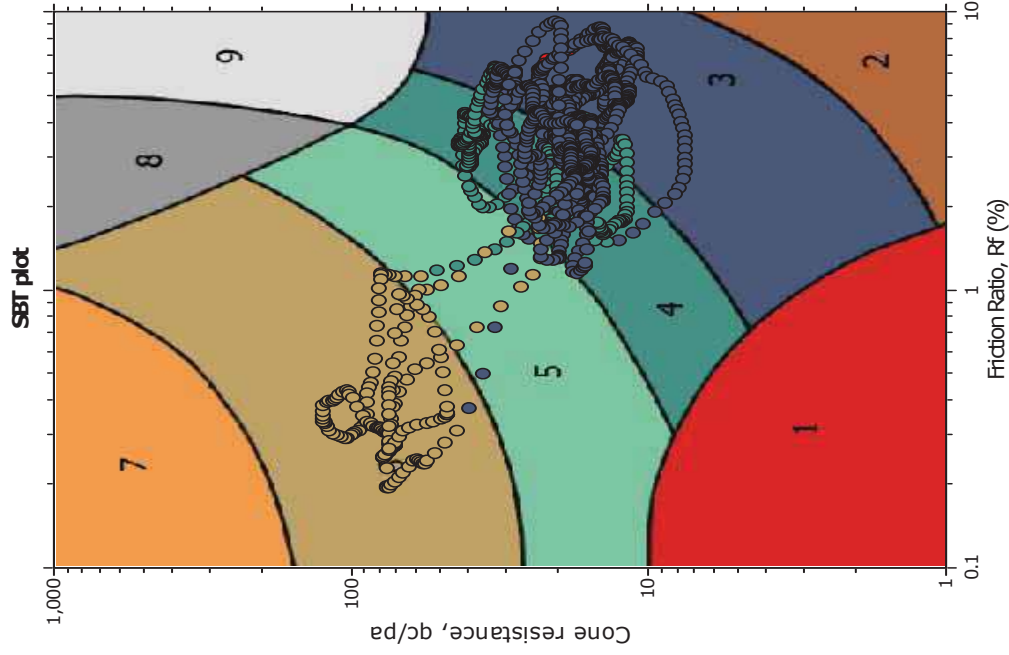
Prove penetrometriche statiche CPTU corredate di interpretazione geotecnica



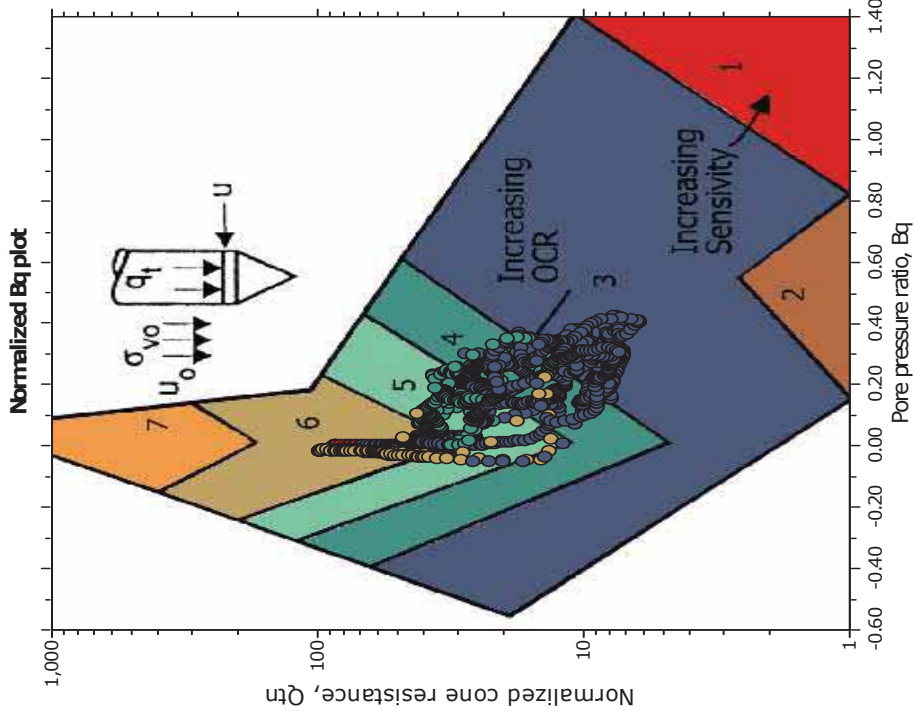
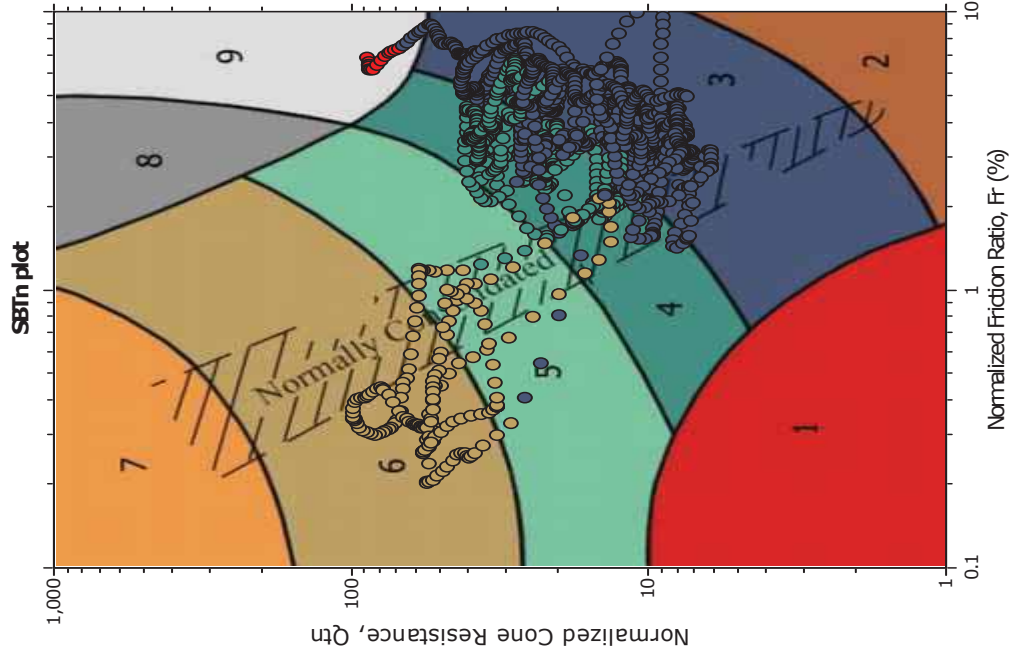
The plot below presents the cross correlation coefficient between the raw q_c and f_s values (as measured on the field). X axes presents the lag distance (one lag is the distance between two successive CPT measurements).



SBT - Bq plots

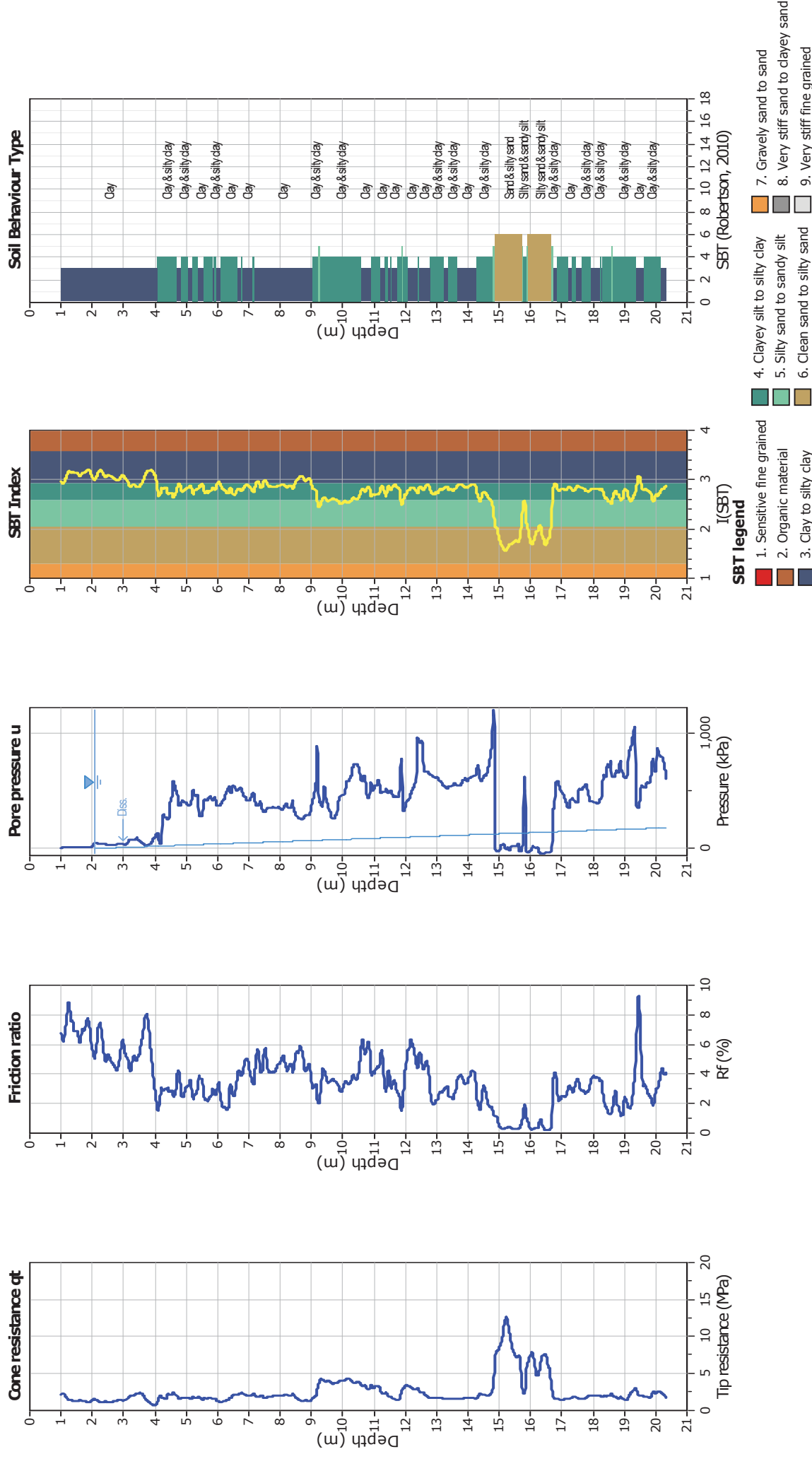


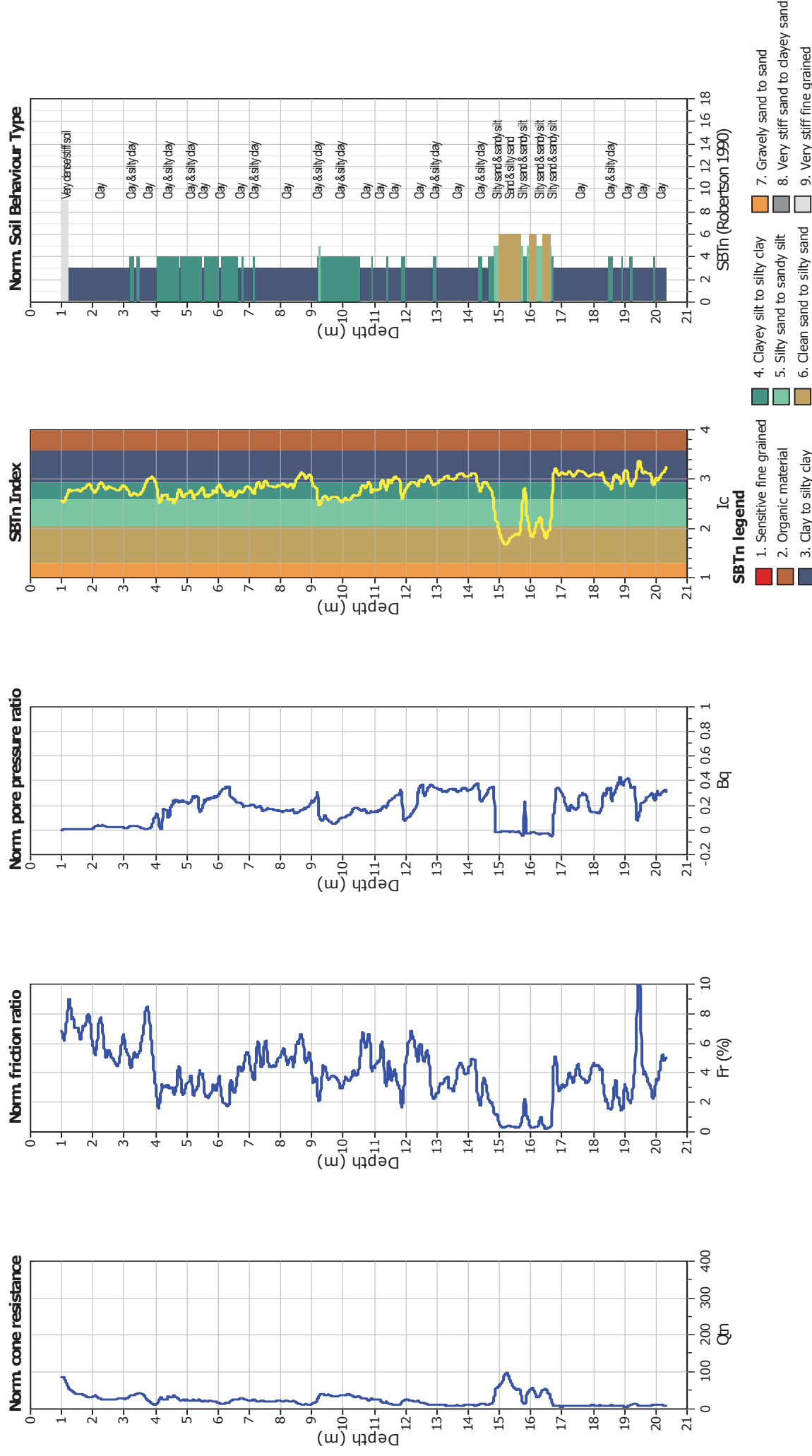
SBT - Bq plots (normalized)

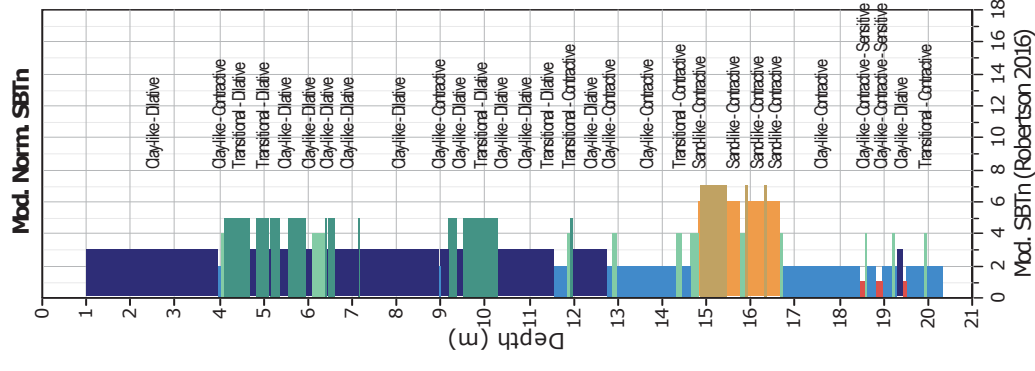
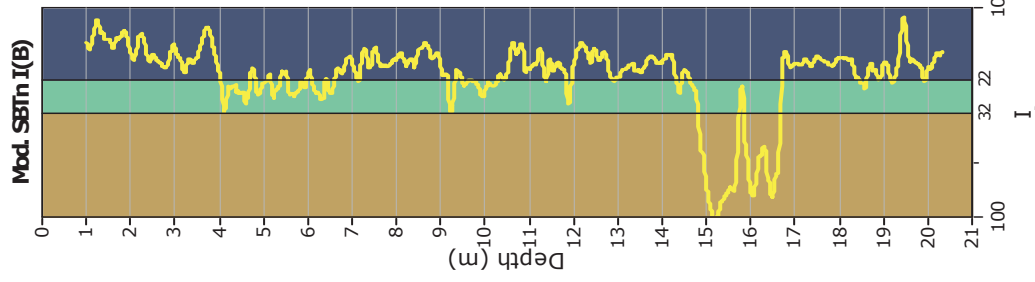
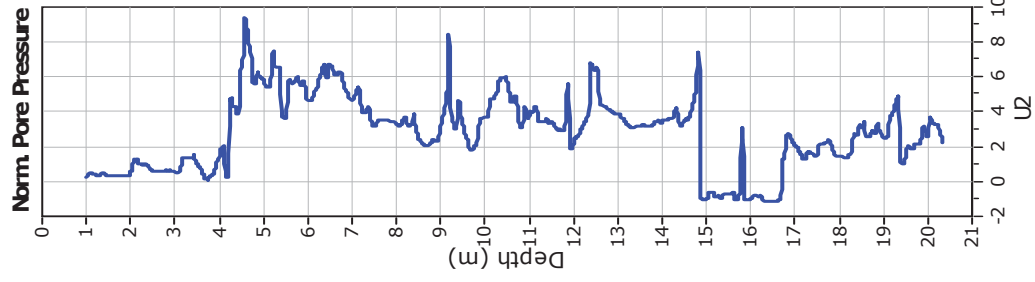
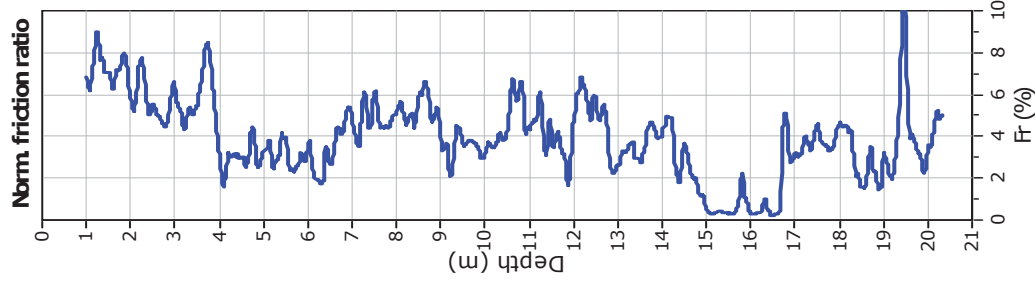
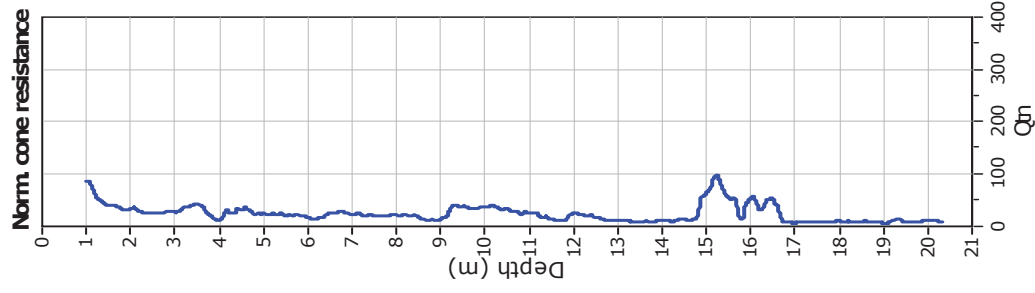


SBTn legend

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



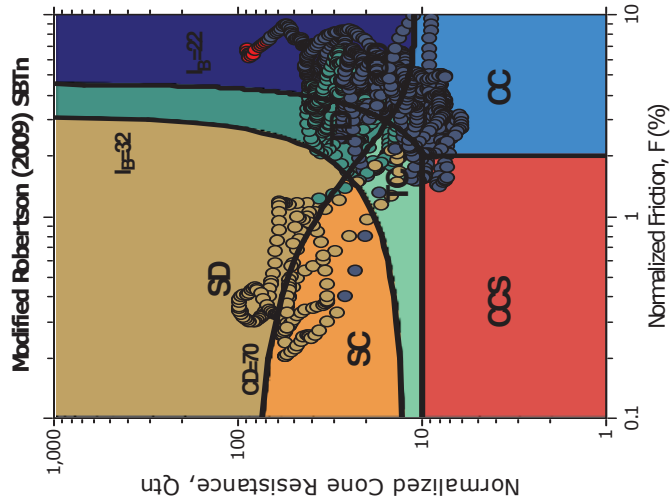




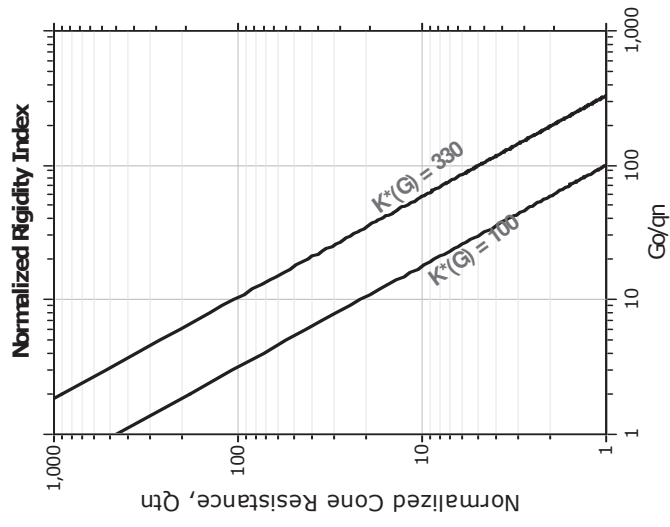
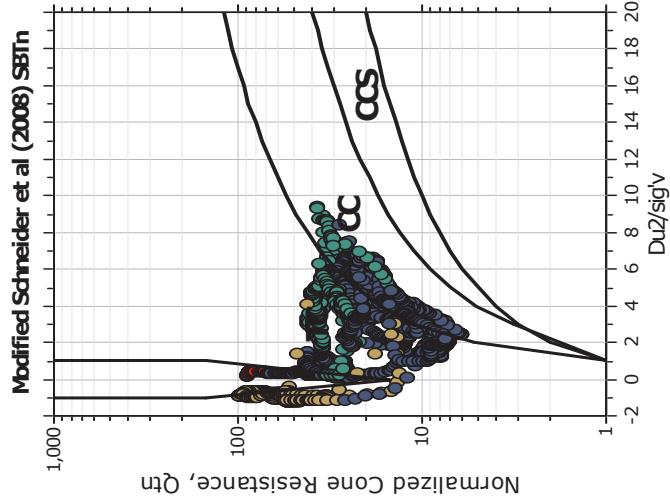
Mod. SBTn legend

- 1. CCS: ClayLike - Contractive, Sensitive
- 2. CC: Clay-like - Contractive
- 3. CD: Clay-Like: Dilative
- 4. TC: Transitional - Contractive
- 5. TD: Transitional - Dilative
- 6. SC: Sand-like - Contractive
- 7. SD: Sand-like - Dilative

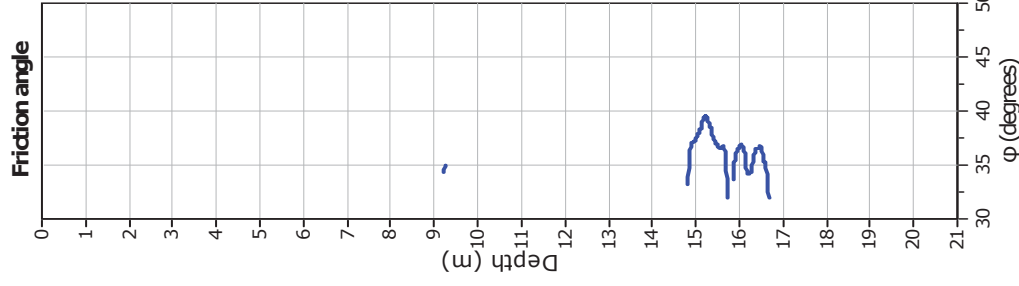
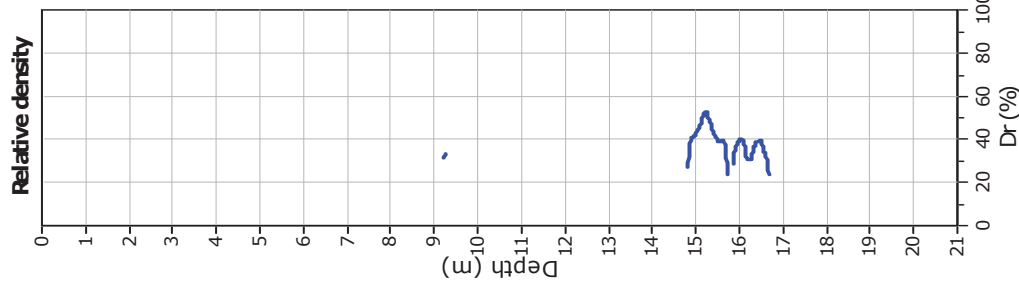
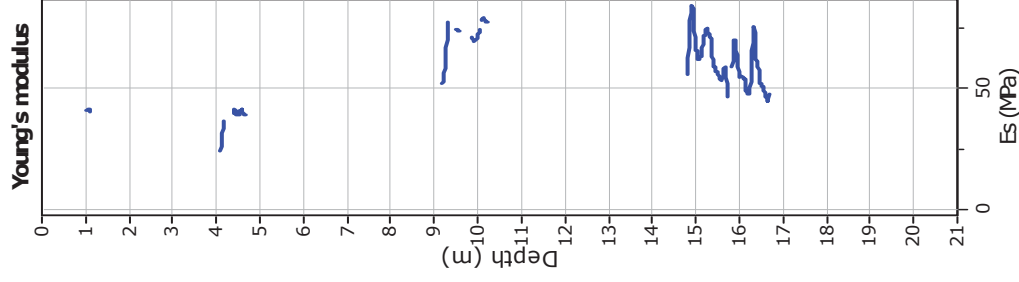
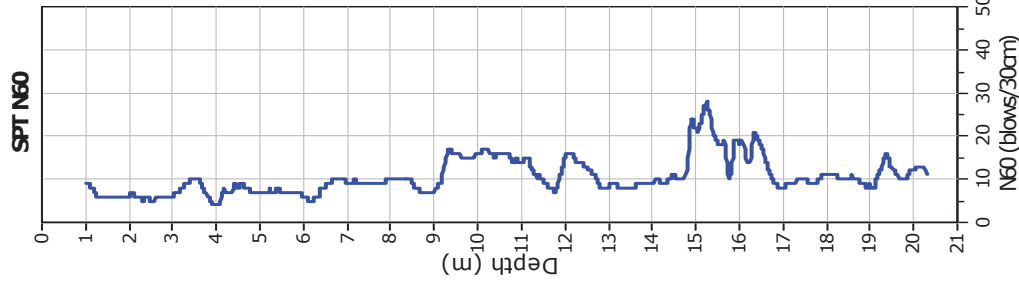
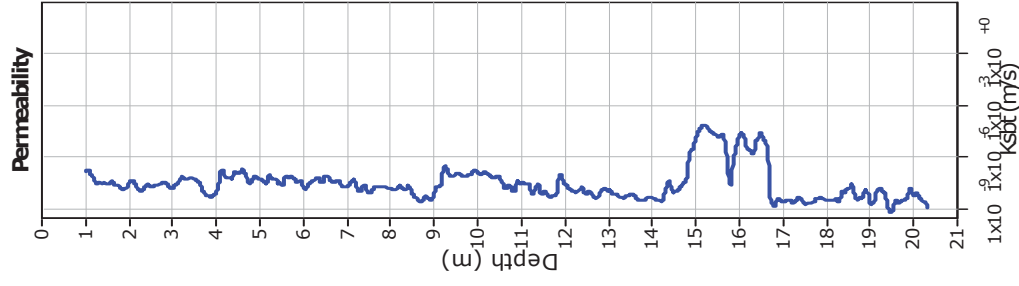
Updated SBTn plots



CCS: Clay-like - Contractive - Sensitive
CC: Clay-like - Contractive
CD: Clay-like - Dilative
TC: Transitional - Contractive
TD: Transitional - Dilative
SC: Sand-like - Contractive
SD: Sand-like - Dilative



$K(G) > 330$: Soils with significant microstructure
(e.g. age/cementation)



Calculation parameters

Permeability: Based on SBT_n

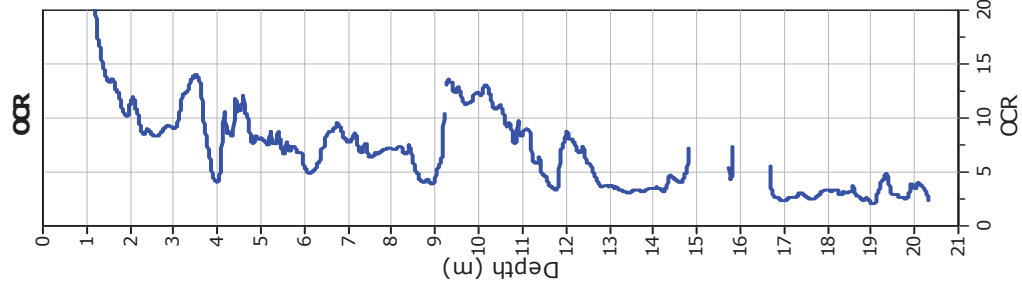
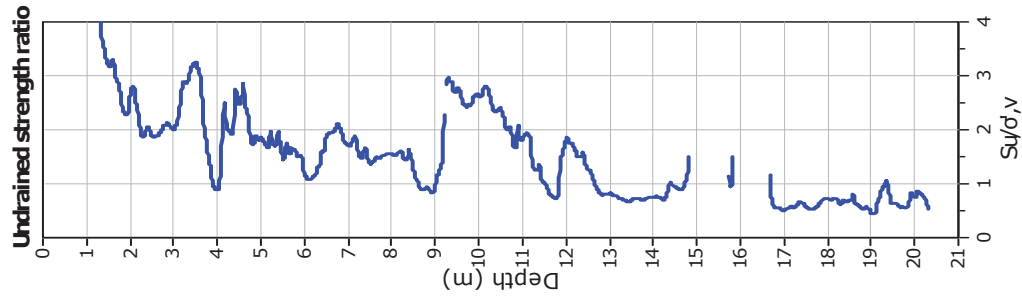
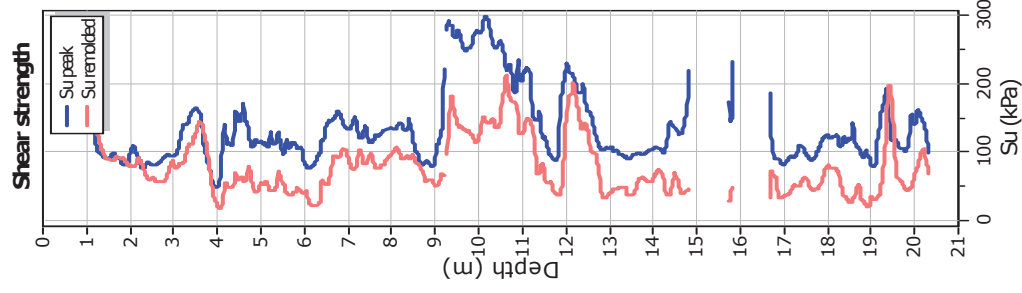
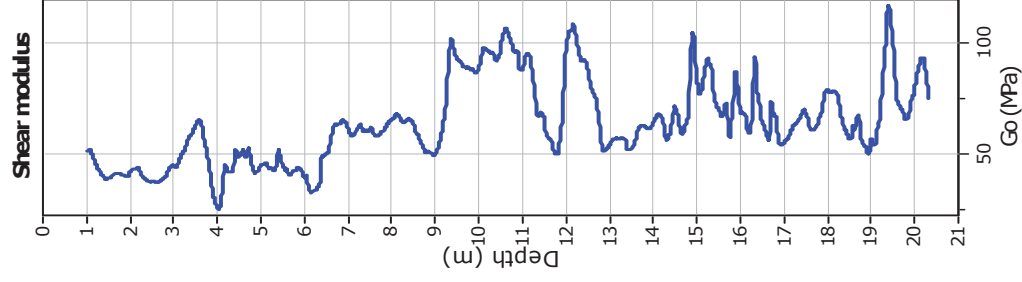
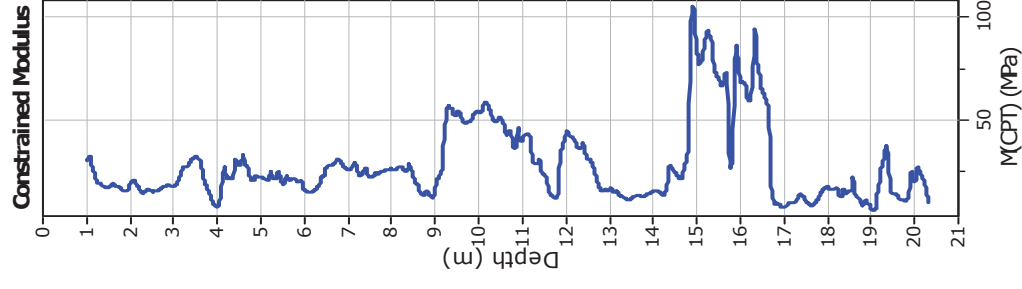
SPT N_{60} : Based on I_c and q_t

Young's modulus: Based on variable alpha using I_c (Robertson, 2009)

Relative density constant, C_{or} : 350.0

Phi: Based on Kulhawy & Mayne (1990)

—●— User defined estimation data



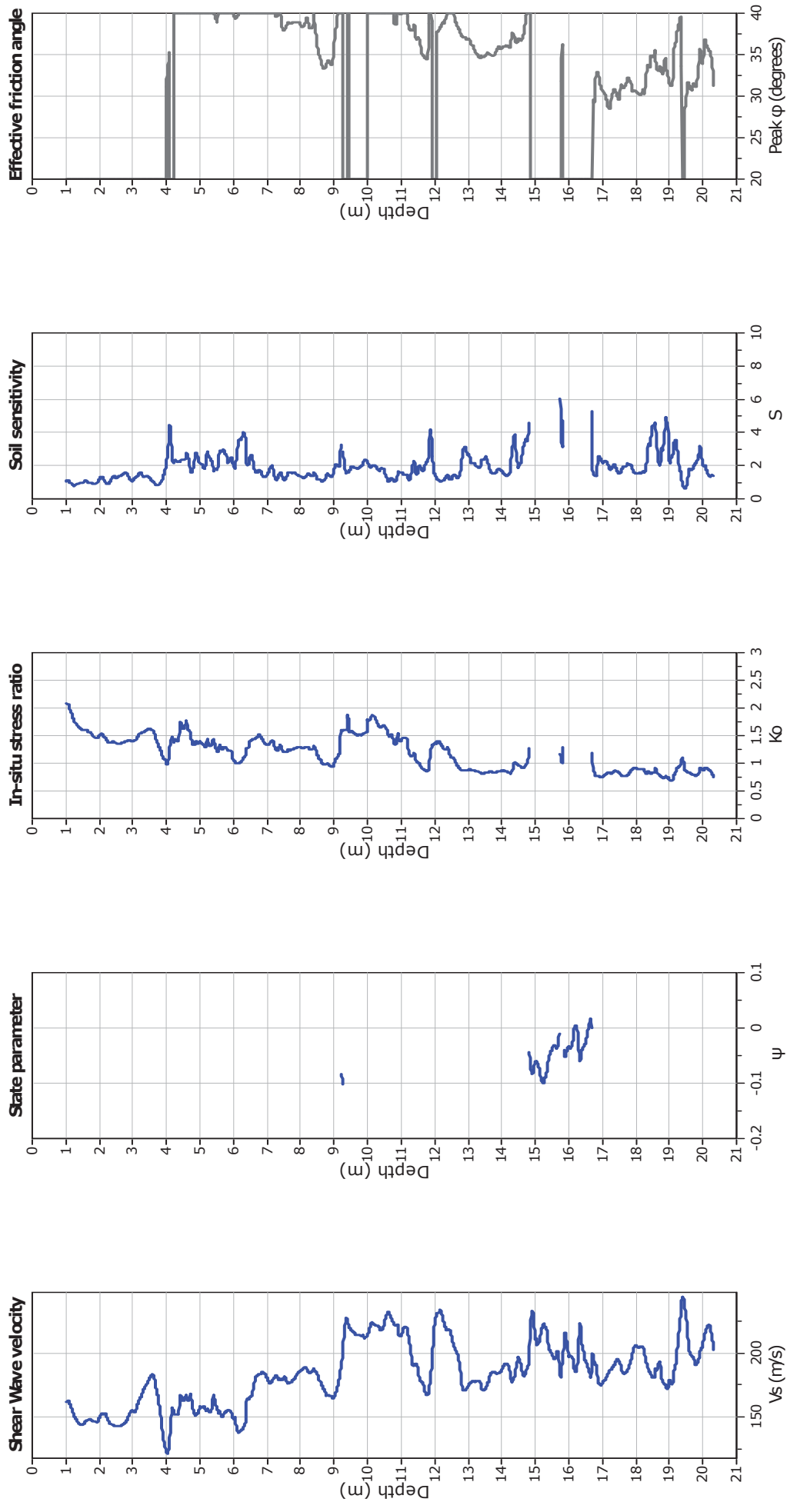
Calculation parameters

Constrained modulus: Based on variable $\alpha/\rho/\lambda$ using I_c and Q_m (Robertson, 2009)
Go: Based on variable $\alpha/\rho/\lambda$ using I_c (Robertson, 2009)

OCR factor for clays, N_{kt} : 0.33

— User defined estimation data
— Flat Dilatometer Test data

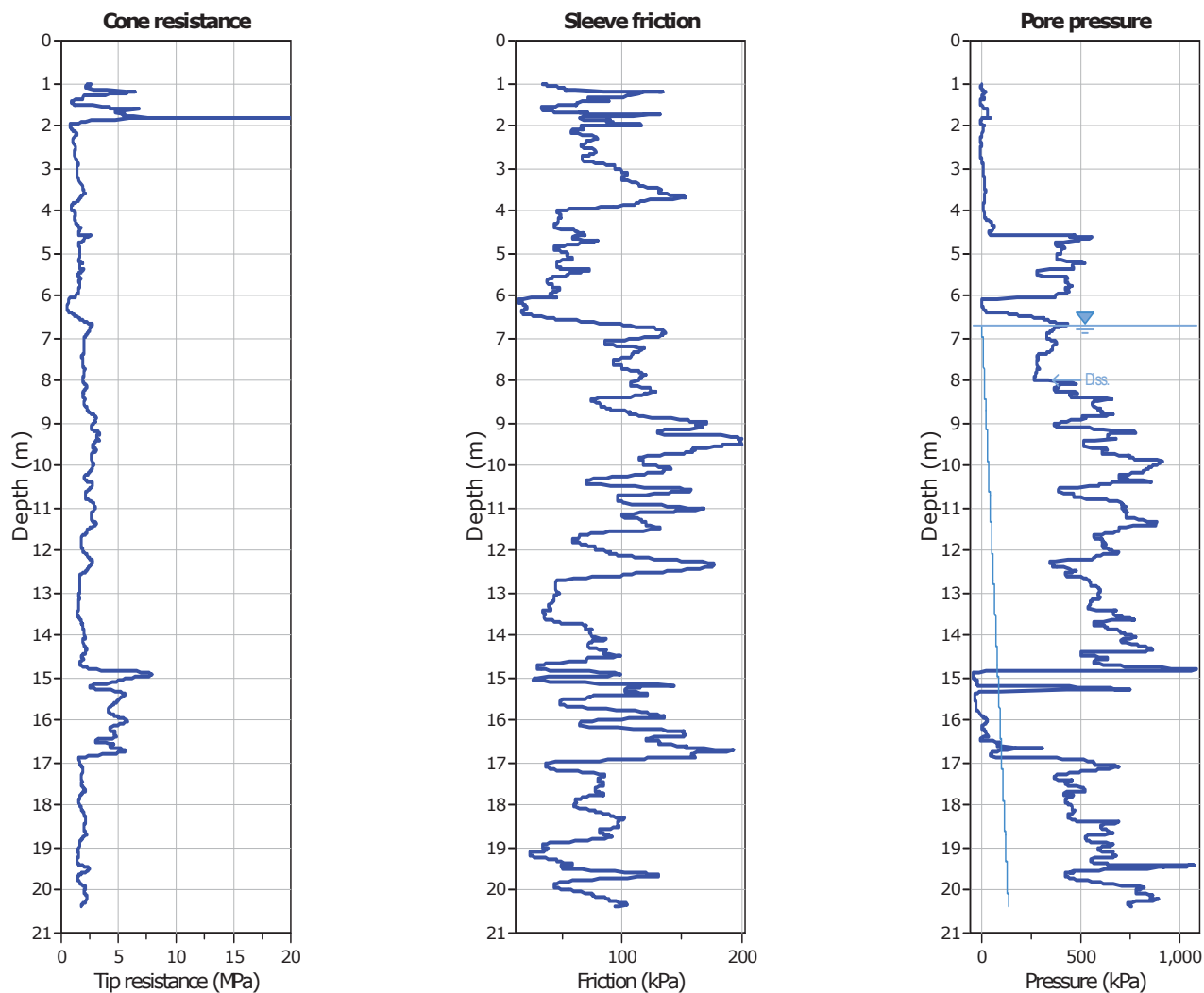
Undrained shear strength cone factor for clays, N_{kt} : 14



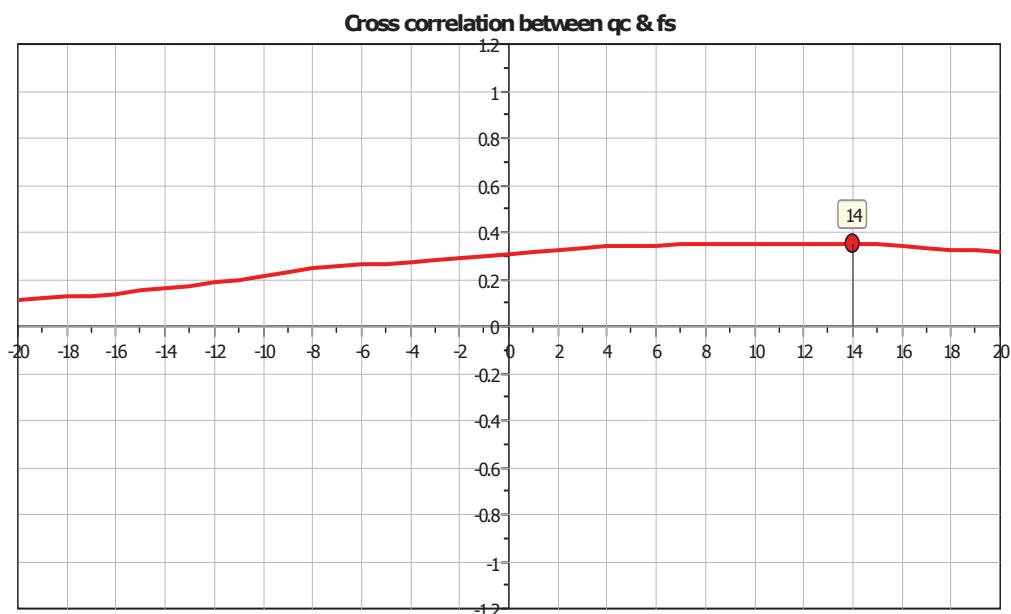
Calculation parameters

Soil Sensitivity factor, N_s : 7.00

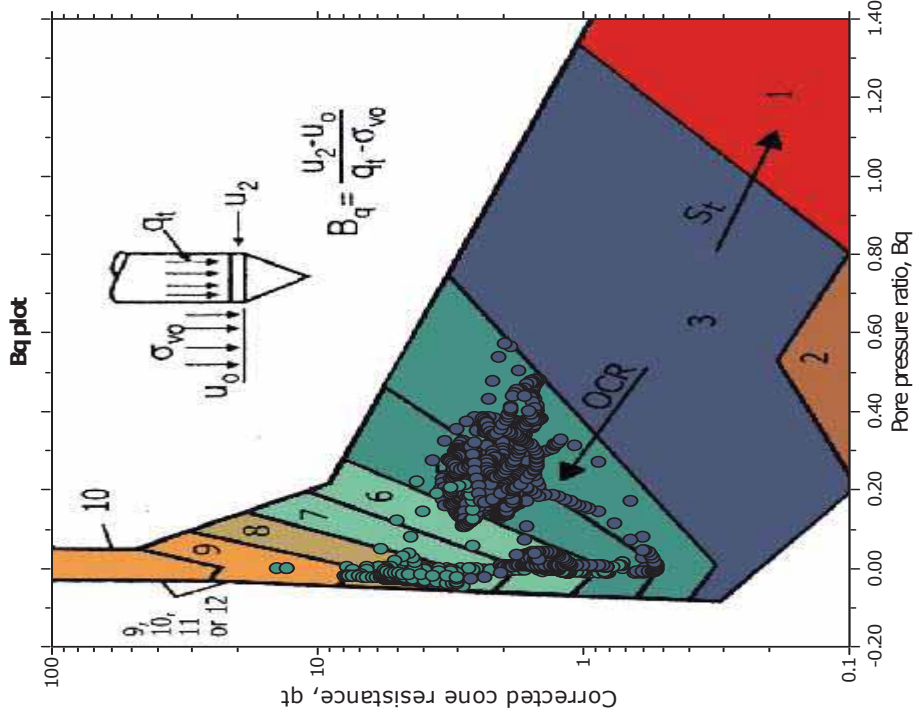
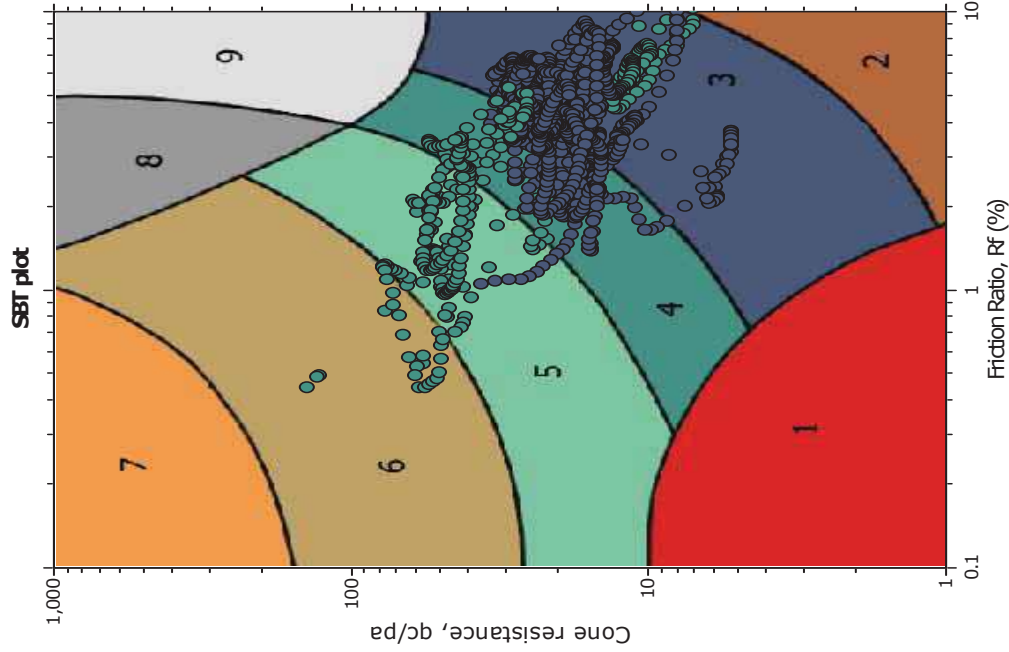
—●— User defined estimation data



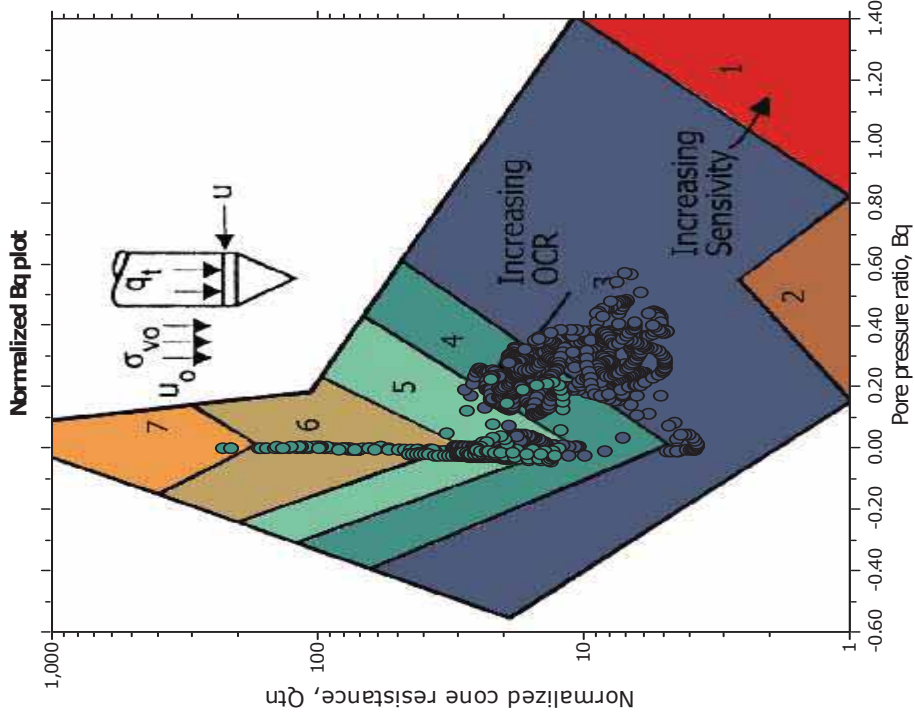
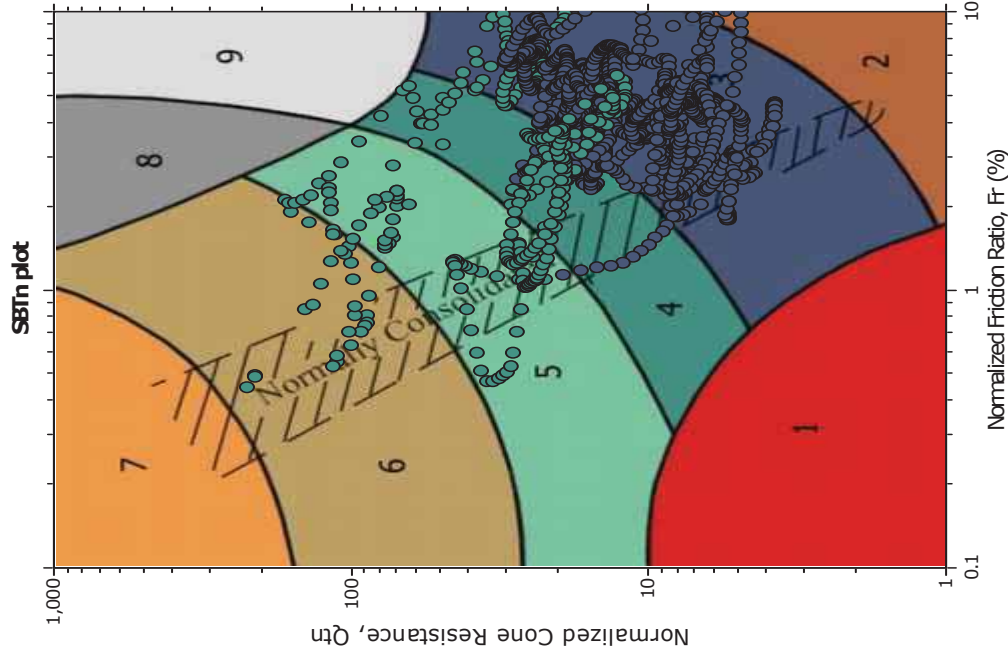
The plot below presents the cross correlation coefficient between the raw q_c and f_s values (as measured on the field). X axes presents the lag distance (one lag is the distance between two successive CPT measurements).



SBT - Bq plots

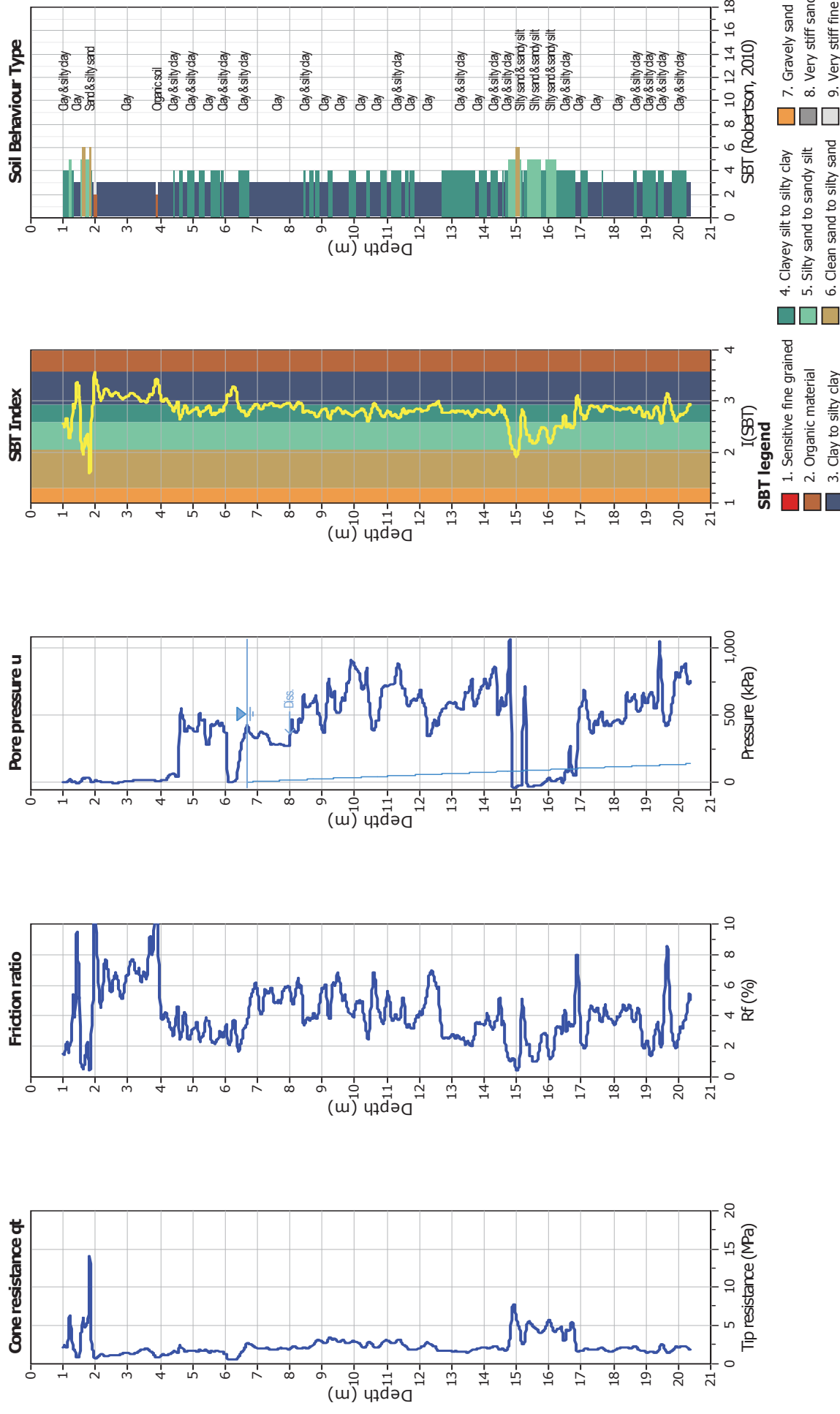


SBT - Bq plots (normalized)



SBTn legend

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

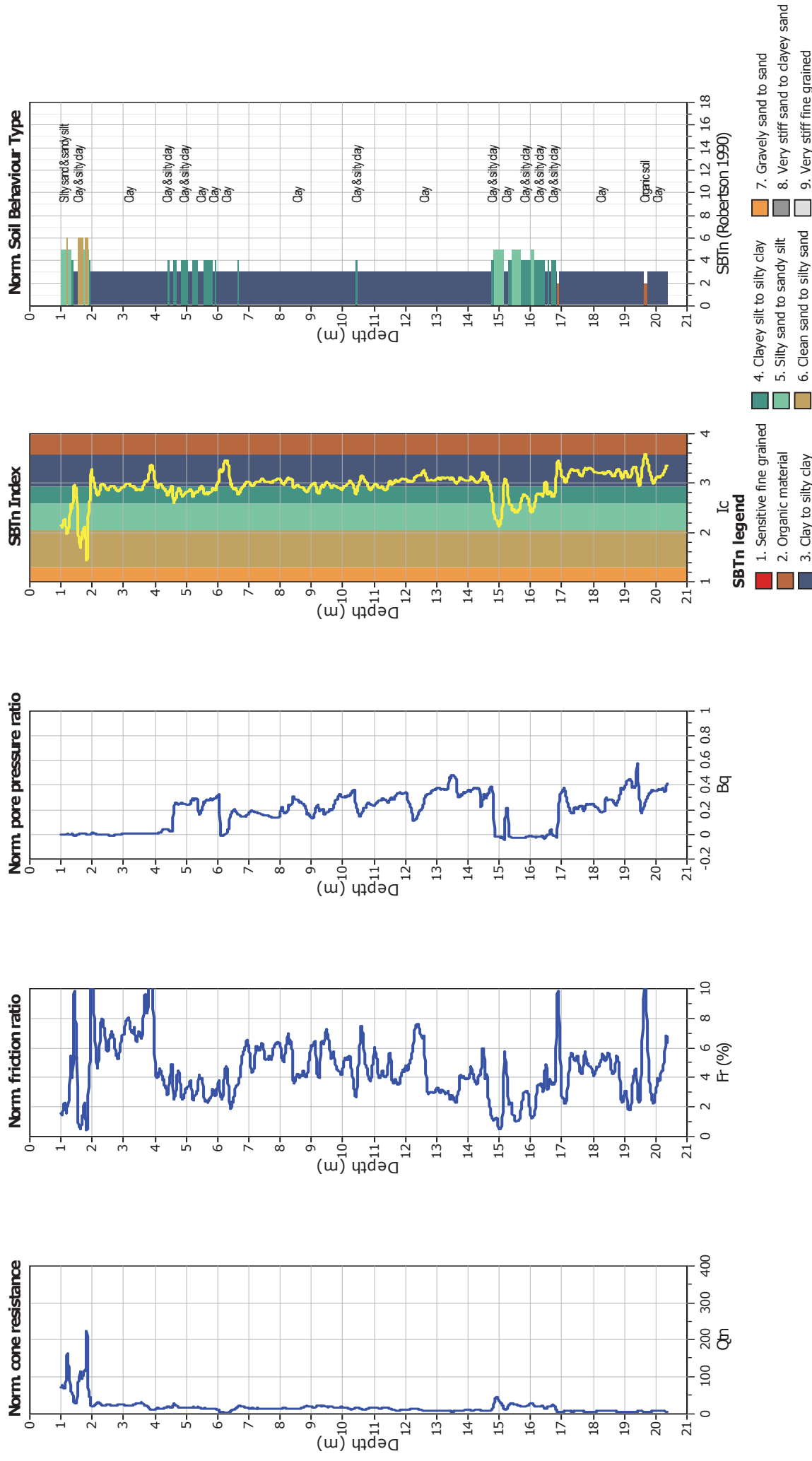


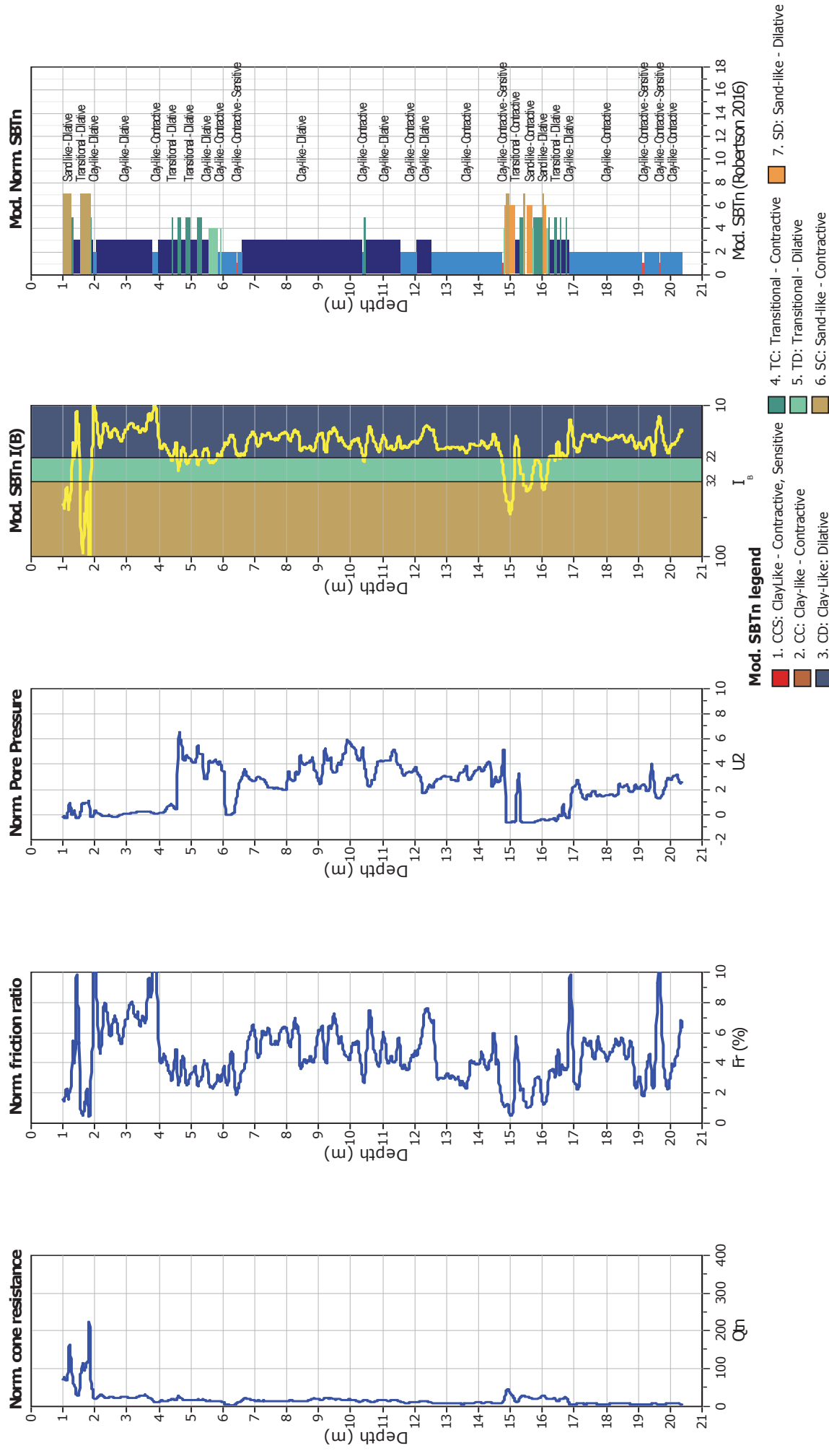


Geo Group S.r.l.
v. per Modena, 12- Castelnuovo Rangone (MO)
059 3967169
info@geogroupmodena.it

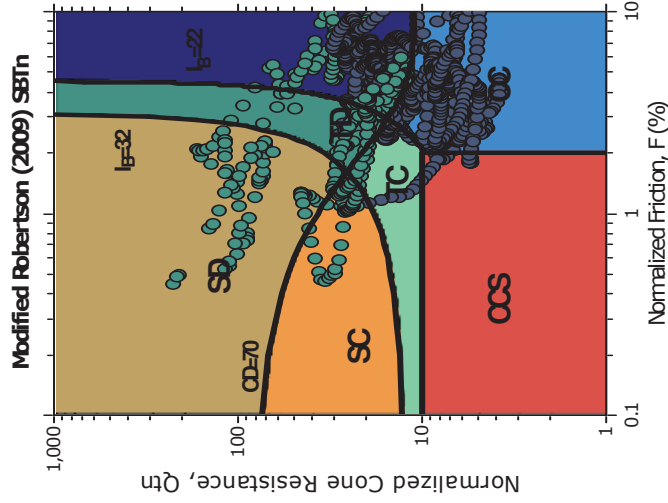
Project: Studio del terreno di fondazione
Location: Fossoli, AIMAG

CPT: CPTU2
Total depth: 20.37 m, Date: 28/10/2021

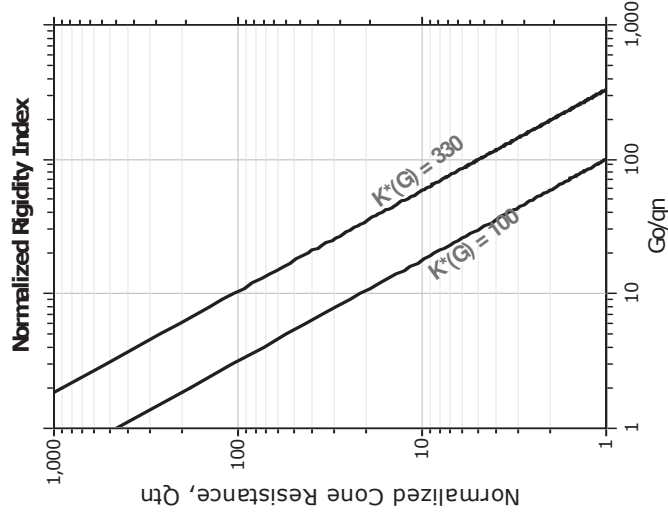
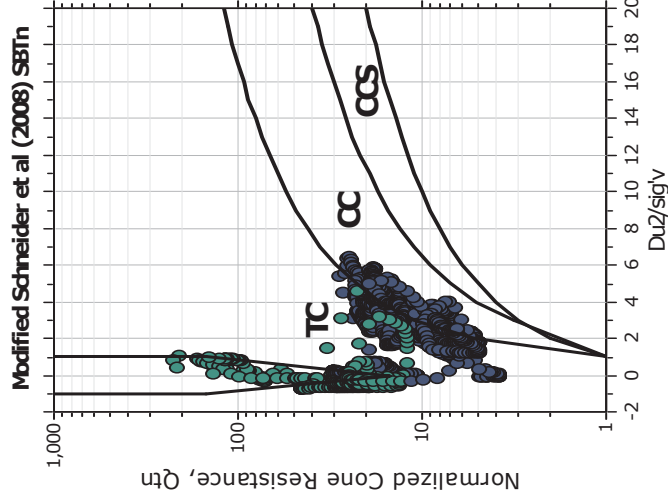




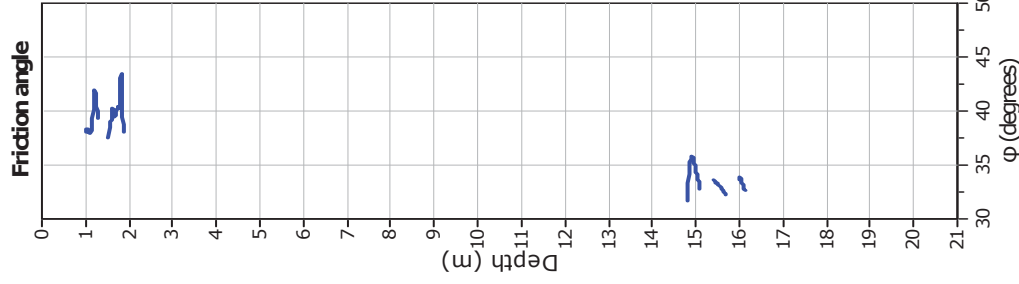
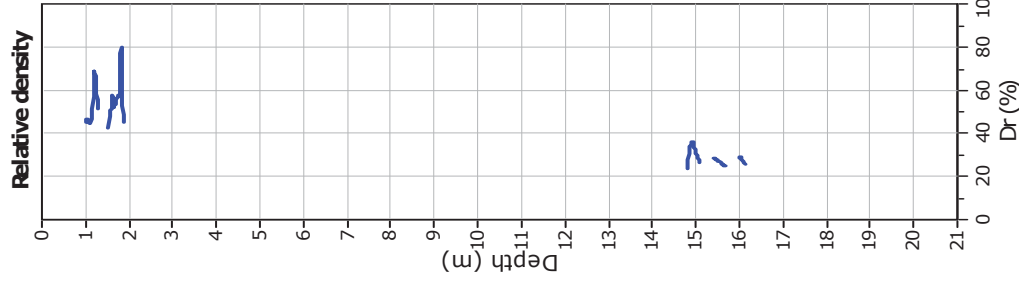
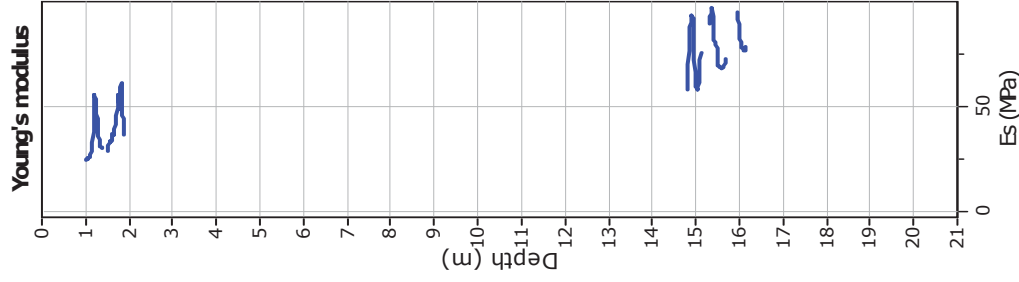
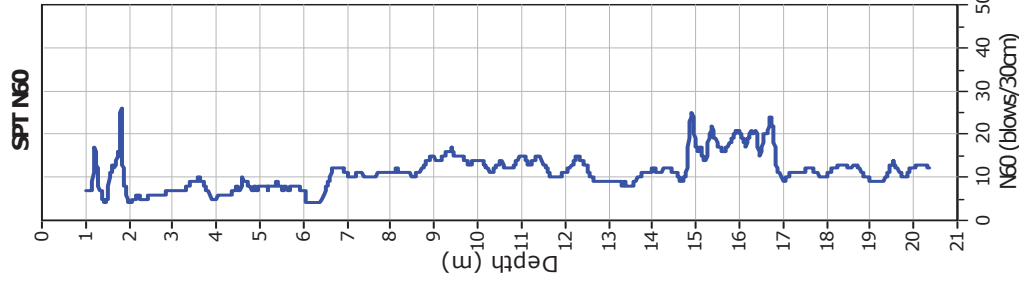
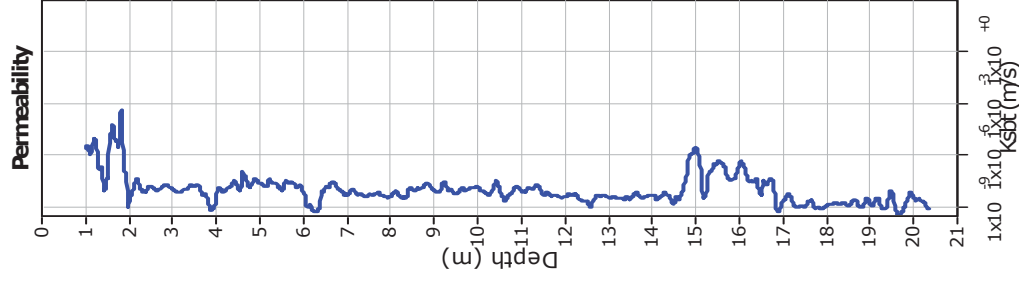
Updated SBTn plots



CCS: Clay-like - Contractive - Sensitive
CC: Clay-like - Contractive
CD: Clay-like - Dilative
TC: Transitional - Contractive
TD: Transitional - Dilative
SC: Sand-like - Contractive
SD: Sand-like - Dilative



$K(G) > 330$: Soils with significant microstructure
(e.g. age/cementation)



Calculation parameters

Permeability: Based on SBT_n

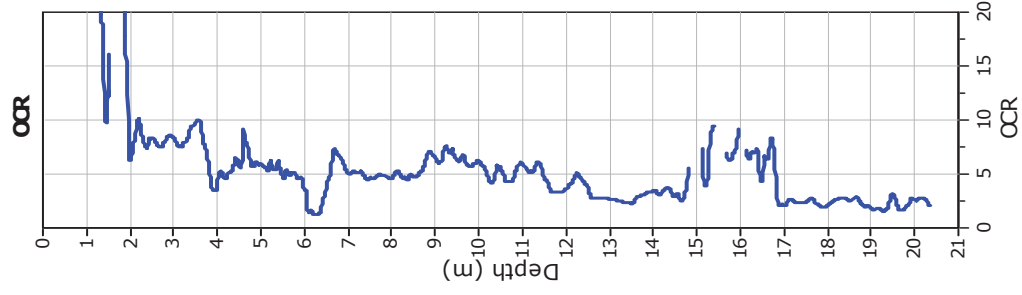
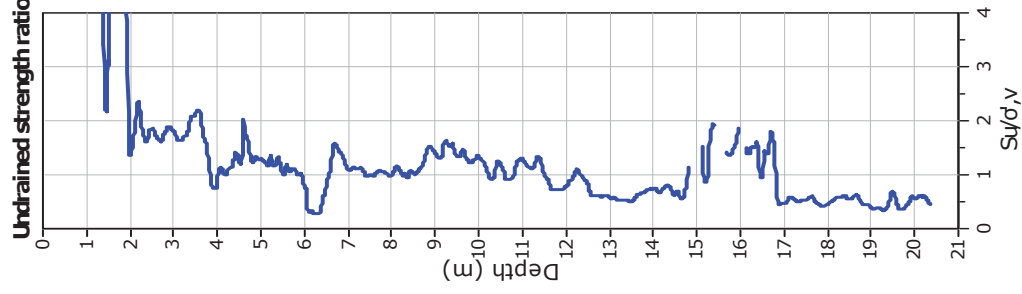
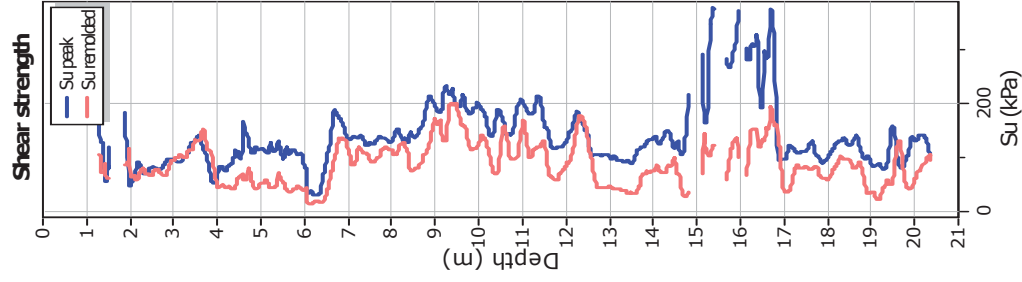
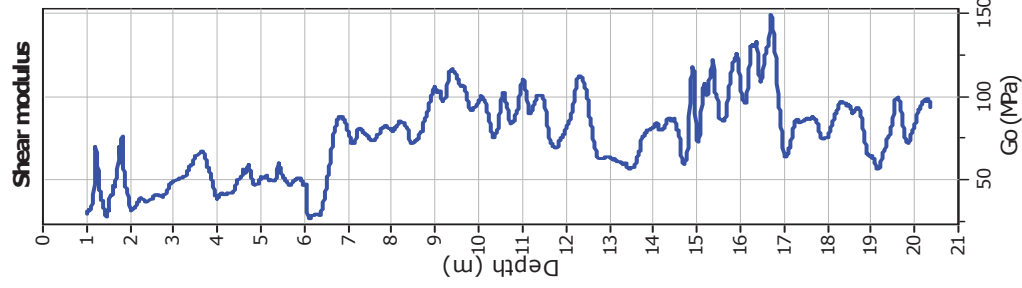
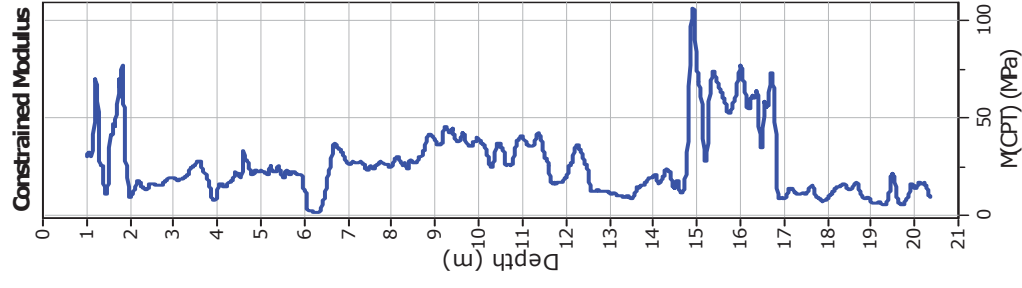
SPT N_{60} : Based on I_c and q_t

Young's modulus: Based on variable alpha using I_c (Robertson, 2009)

Relative density constant, C_{or} : 350.0

Phi: Based on Kulhawy & Mayne (1990)

—●— User defined estimation data

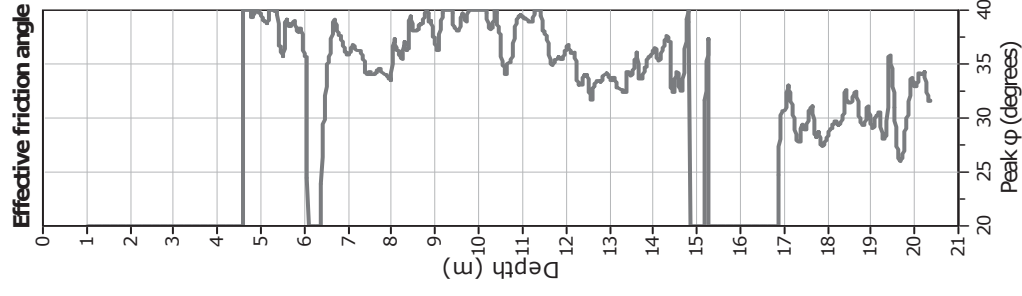
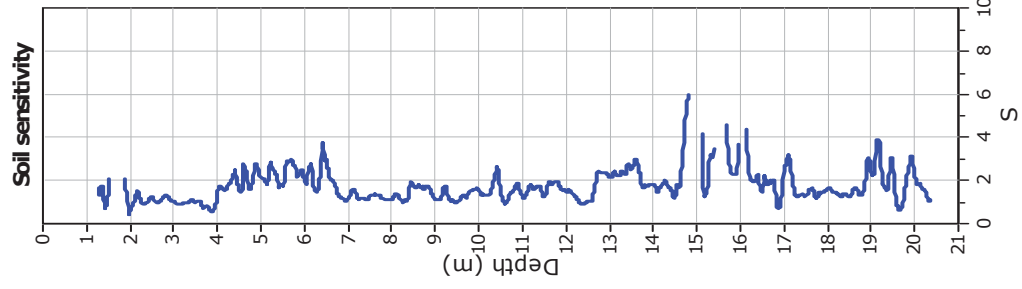
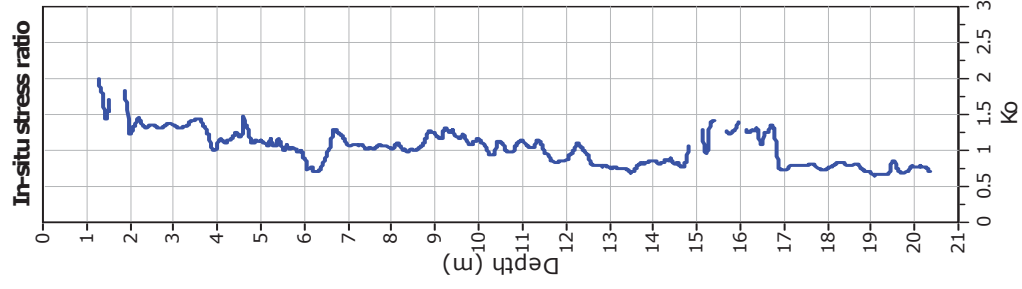
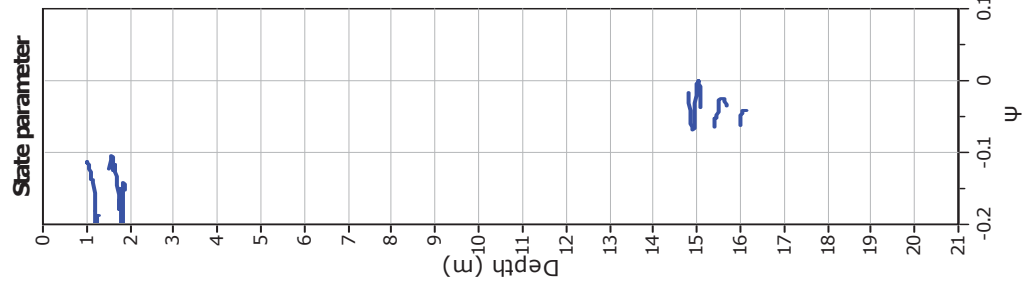
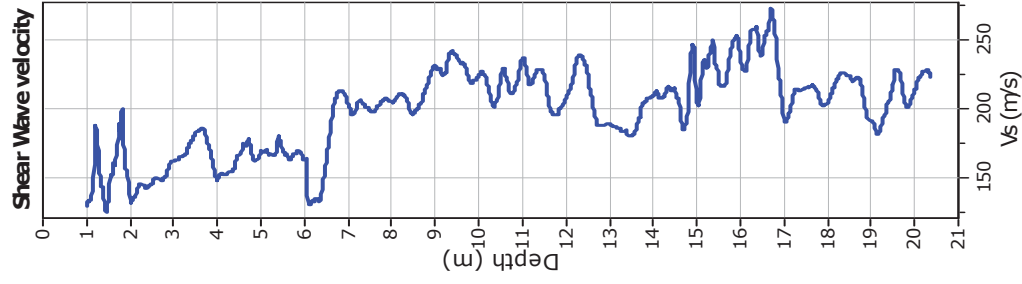


Calculation parameters

Constrained modulus: Based on variable $\alpha/\rho/\eta$ using I_c and Q_m (Robertson, 2009)
Go: Based on variable $\alpha/\rho/\eta$ using I_c (Robertson, 2009)

OCR factor for clays, N_{kt} : 0.33
—●— User defined estimation data
—●— Flat Dilatometer Test data

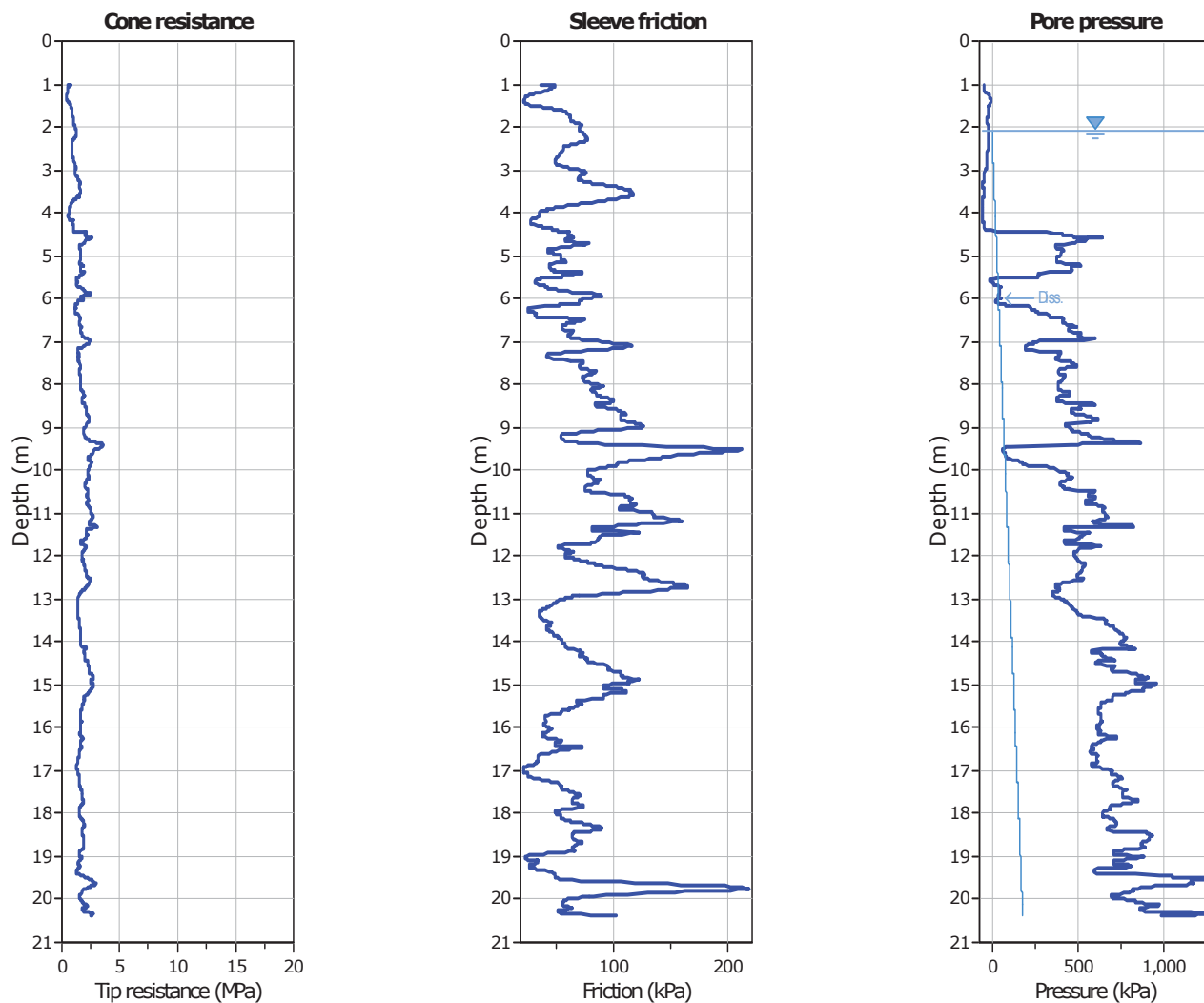
Undrained shear strength cone factor for clays, N_{kt} : 14



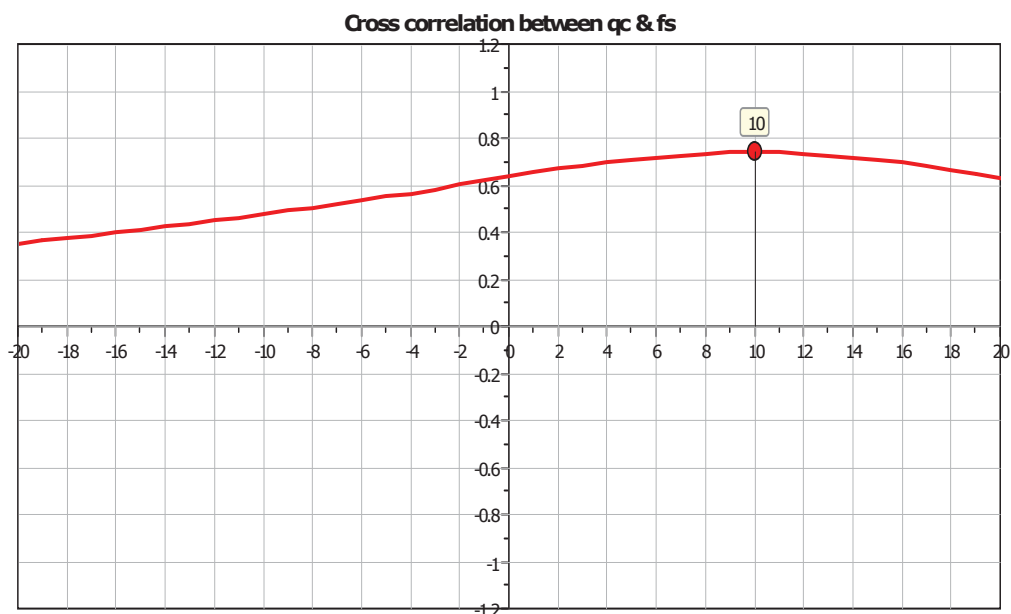
Calculation parameters

Soil Sensitivity factor, N_s : 7.00

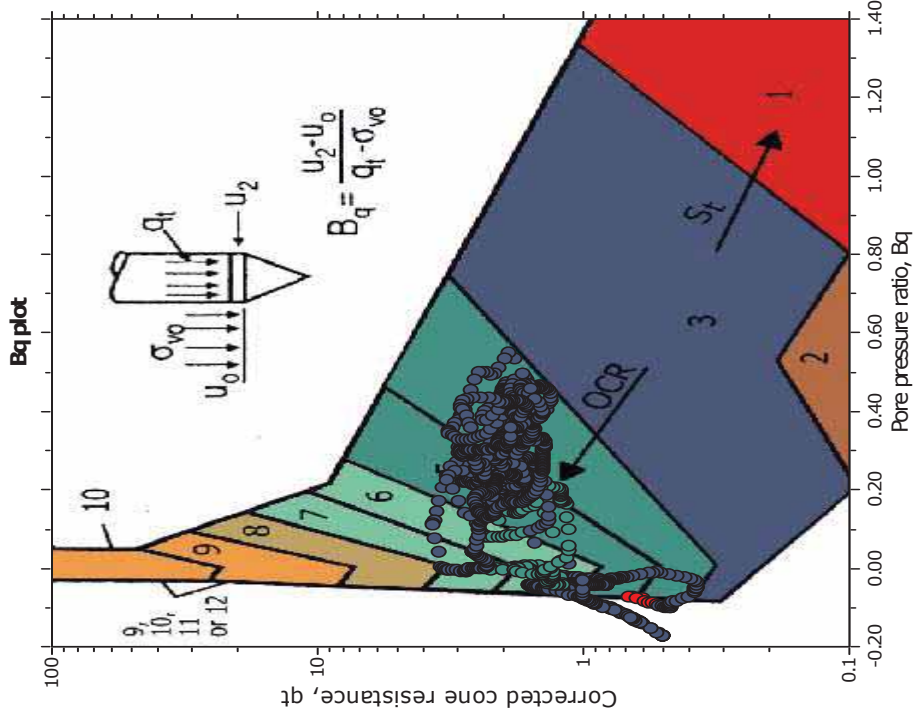
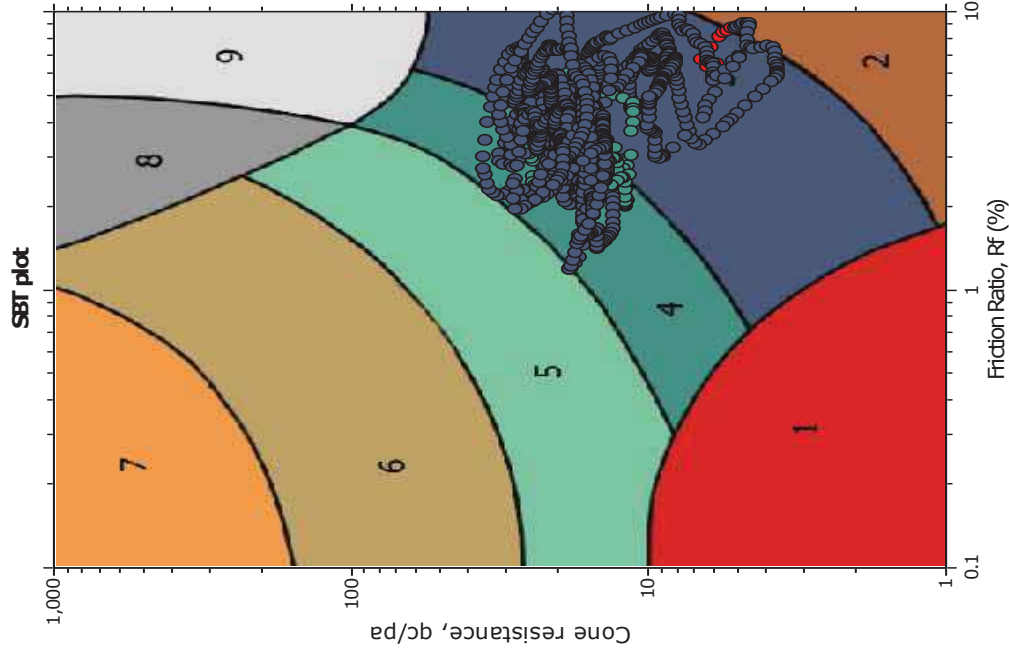
—●— User defined estimation data



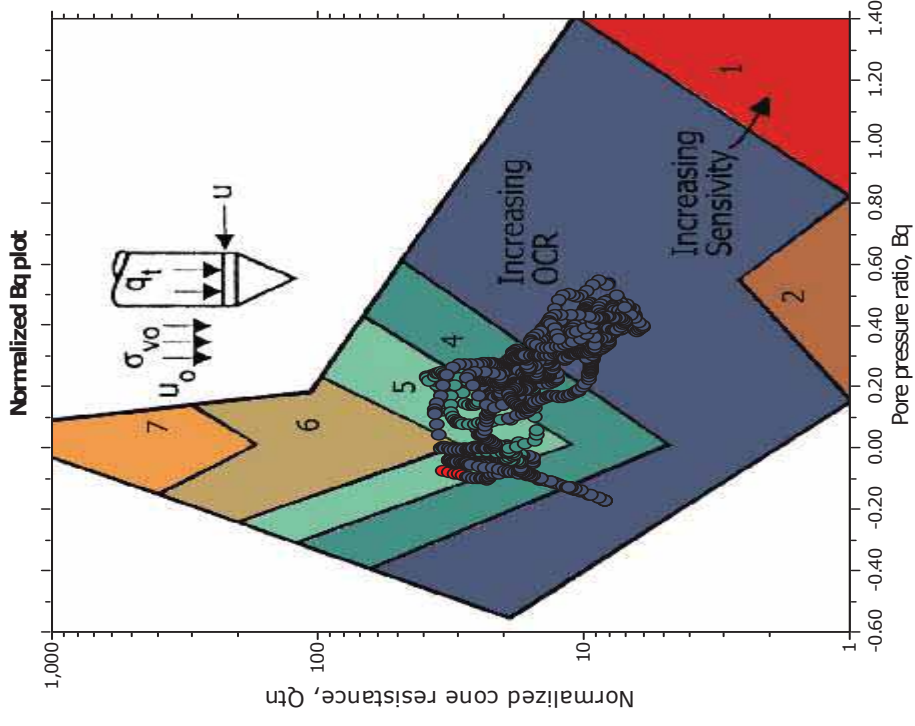
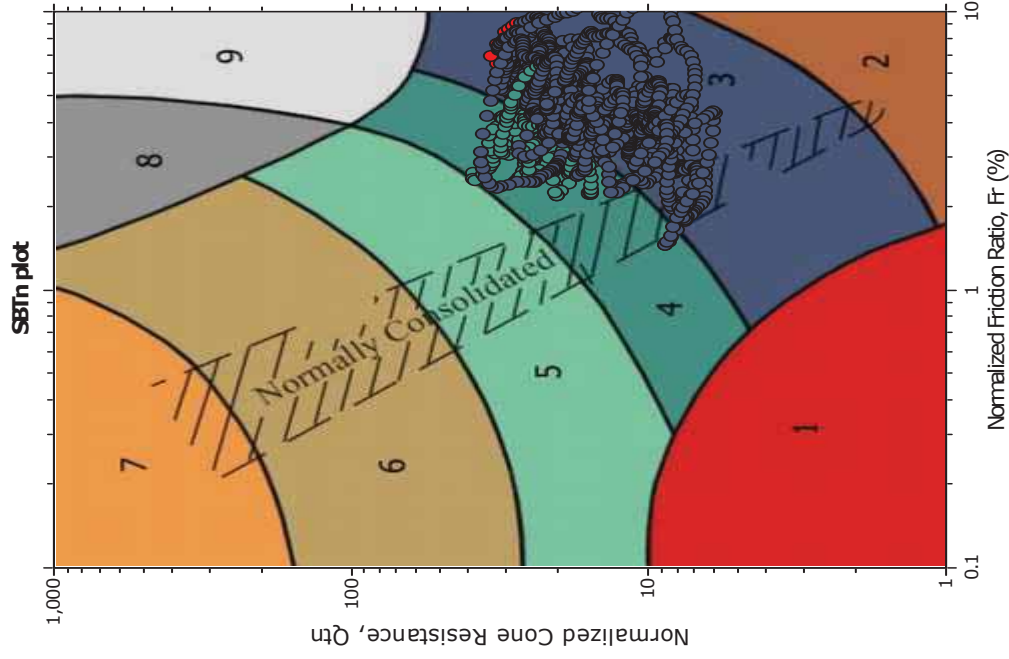
The plot below presents the cross correlation coefficient between the raw q_c and f_s values (as measured on the field). X axes presents the lag distance (one lag is the distance between two successive CPT measurements).



SBT - Bq plots

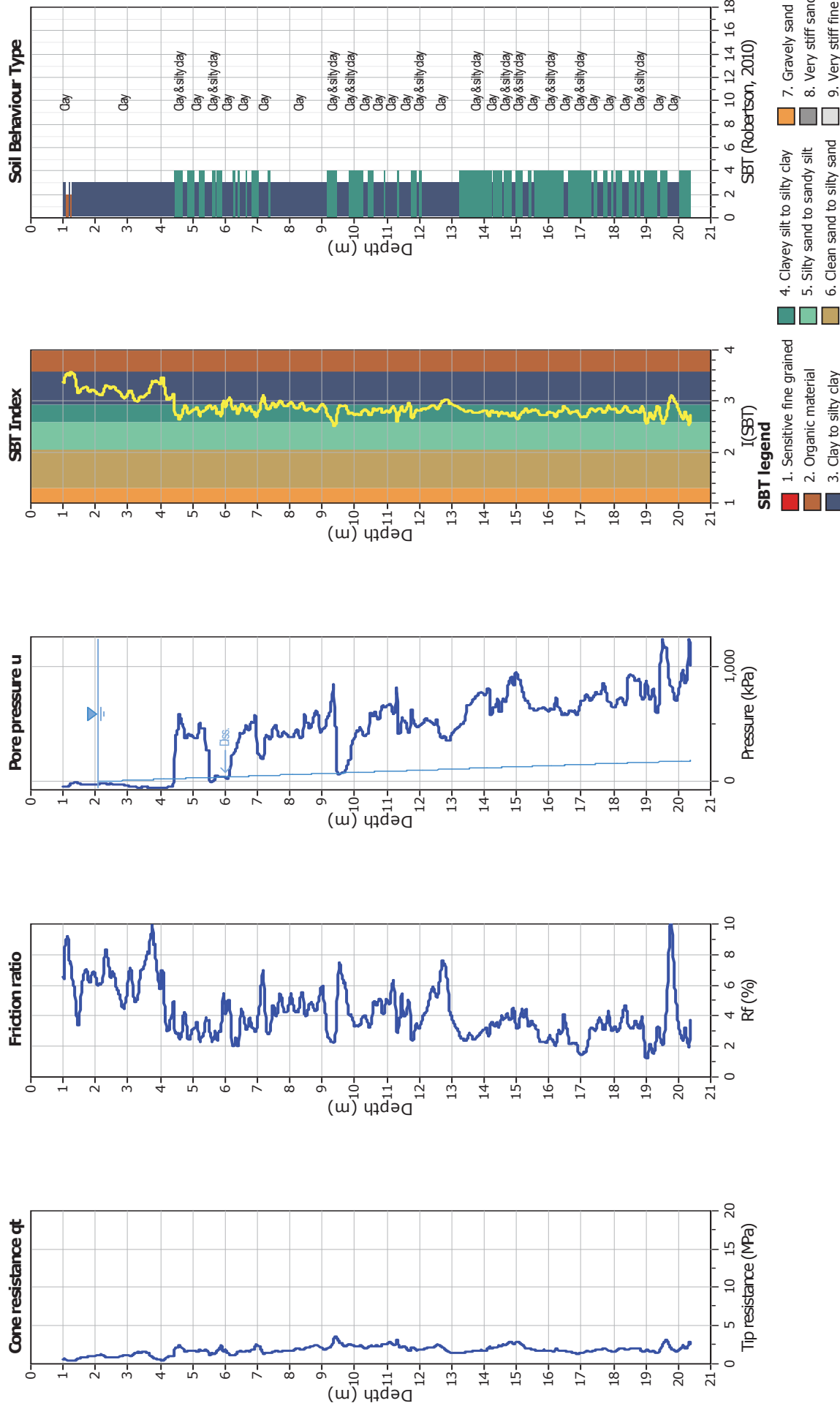


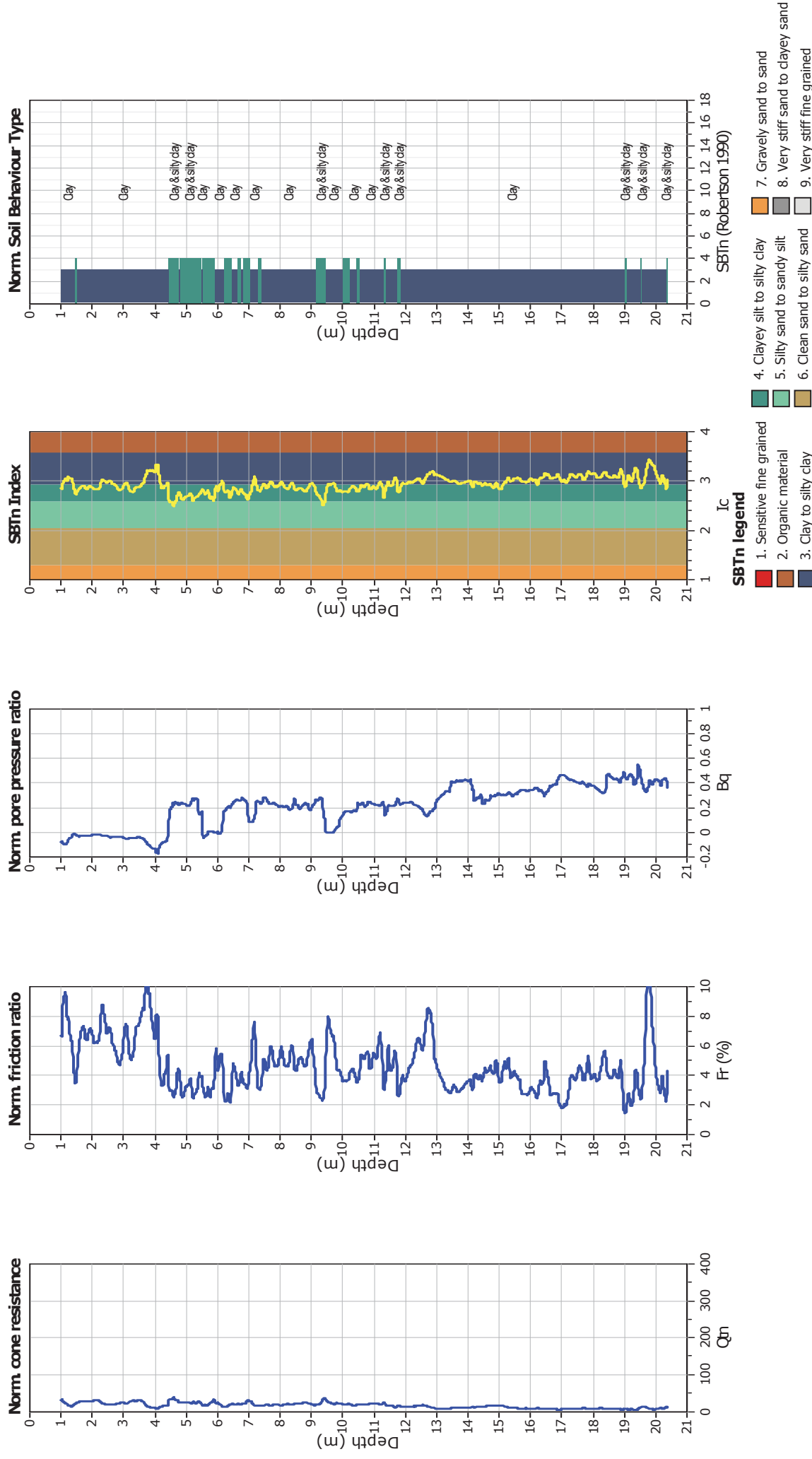
SBT - Bq plots (normalized)

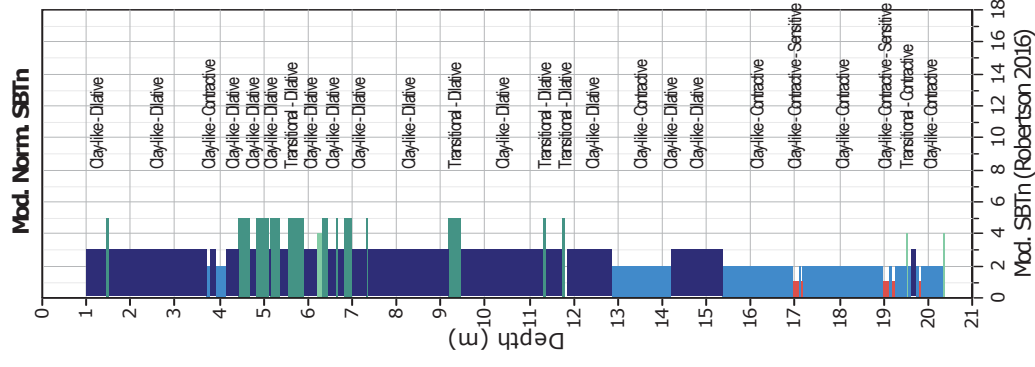
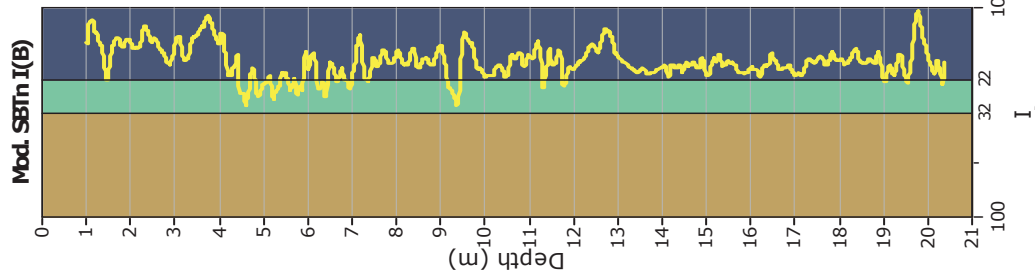
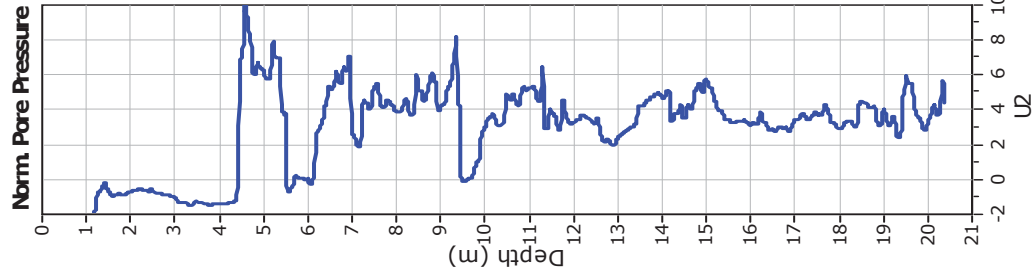
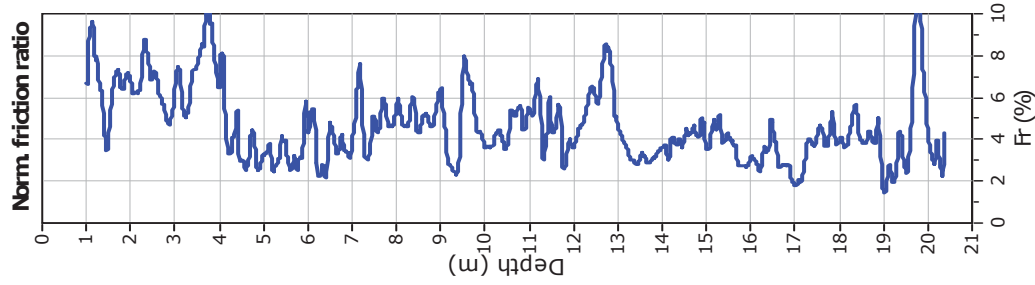
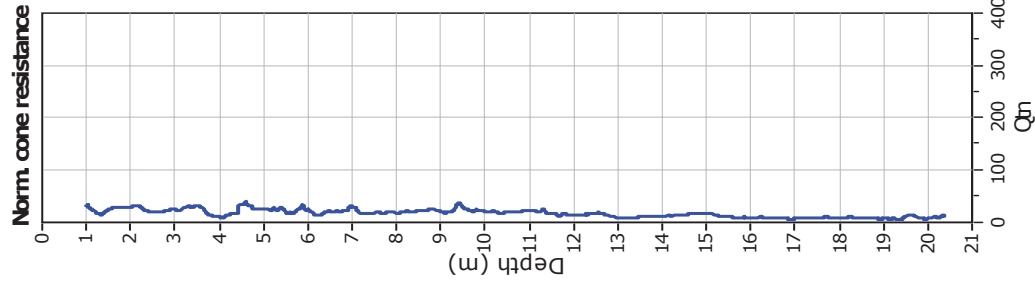


SBTn legend

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



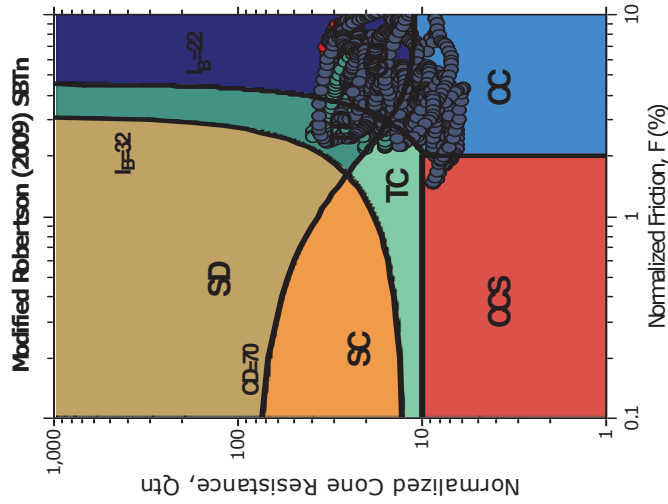




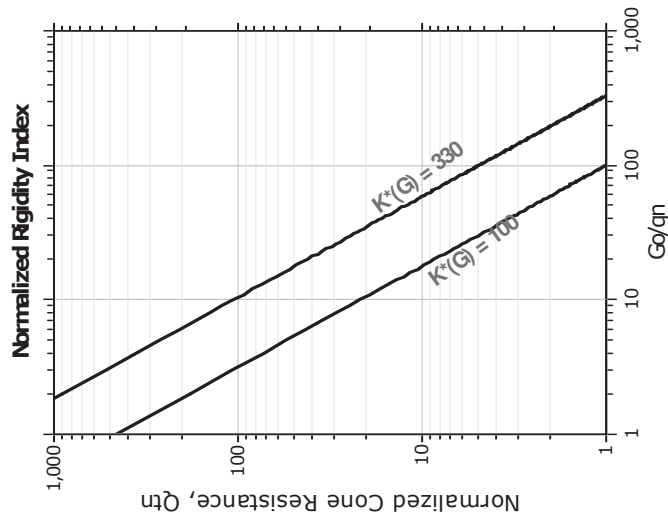
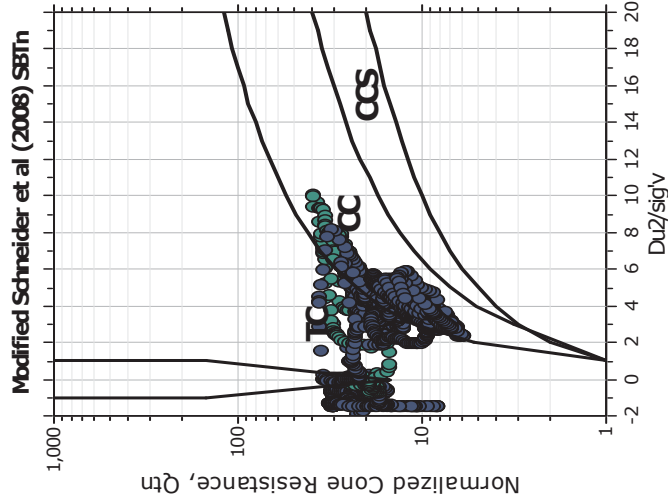
Mod. SBTn legend

- 1. CCS: ClayLike - Contractive, Sensitive
- 2. CC: Clay-like - Contractive
- 3. CD: Clay-Like: Dilative
- 4. TC: Transitional - Contractive
- 5. TD: Transitional - Dilative
- 6. SC: Sand-like - Contractive
- 7. SD: Sand-like - Dilative

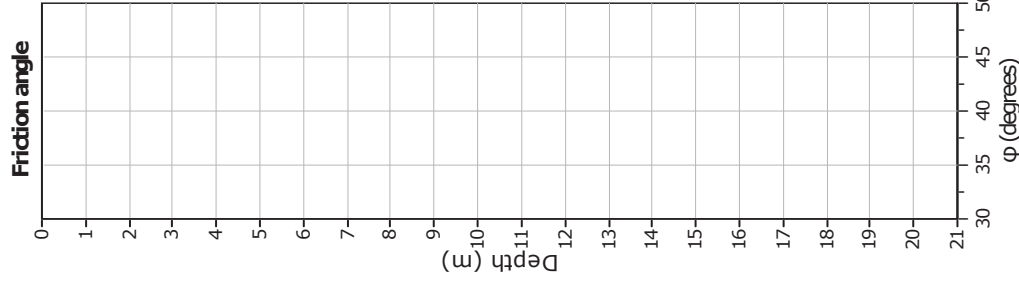
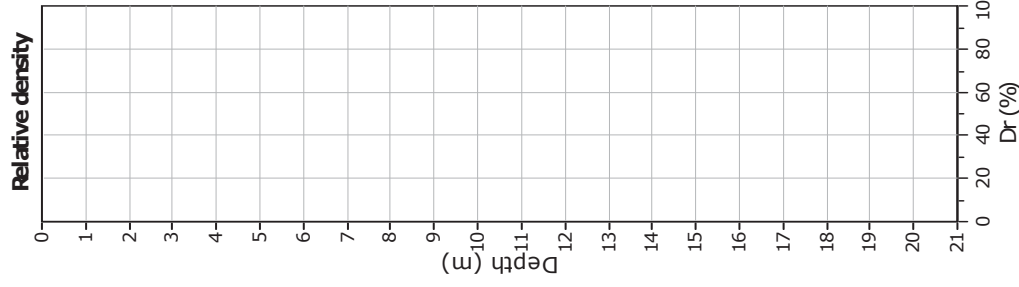
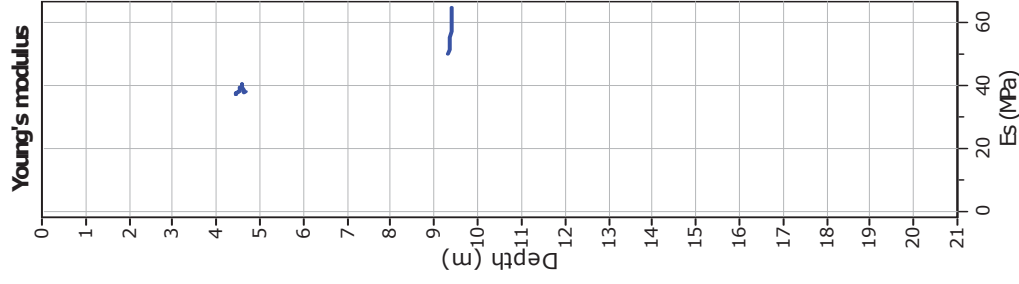
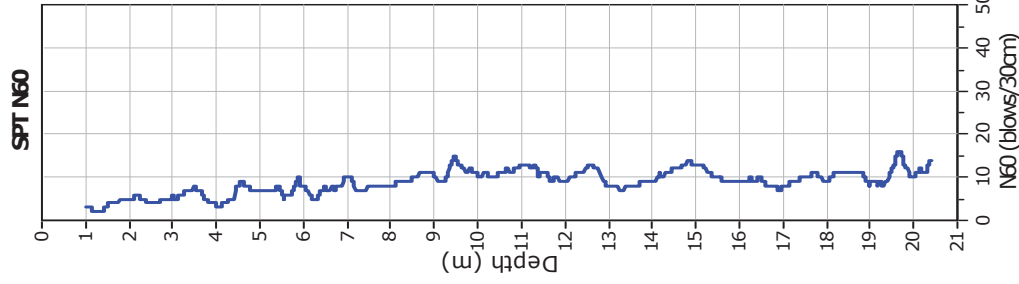
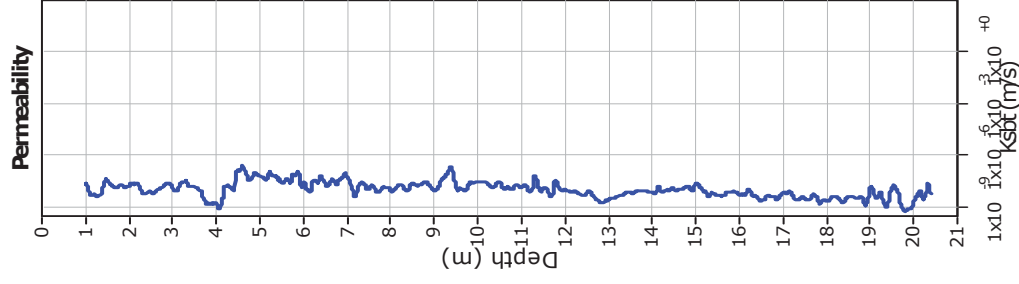
Updated SBTn plots



CCS: Clay-like - Contractive - Sensitive
CC: Clay-like - Contractive
CD: Clay-like - Dilative
TC: Transitional - Contractive
TD: Transitional - Dilative
SC: Sand-like - Contractive
SD: Sand-like - Dilative



$K(G) > 330$: Soils with significant microstructure
(e.g. age/cementation)



Calculation parameters

Permeability: Based on SBT_n

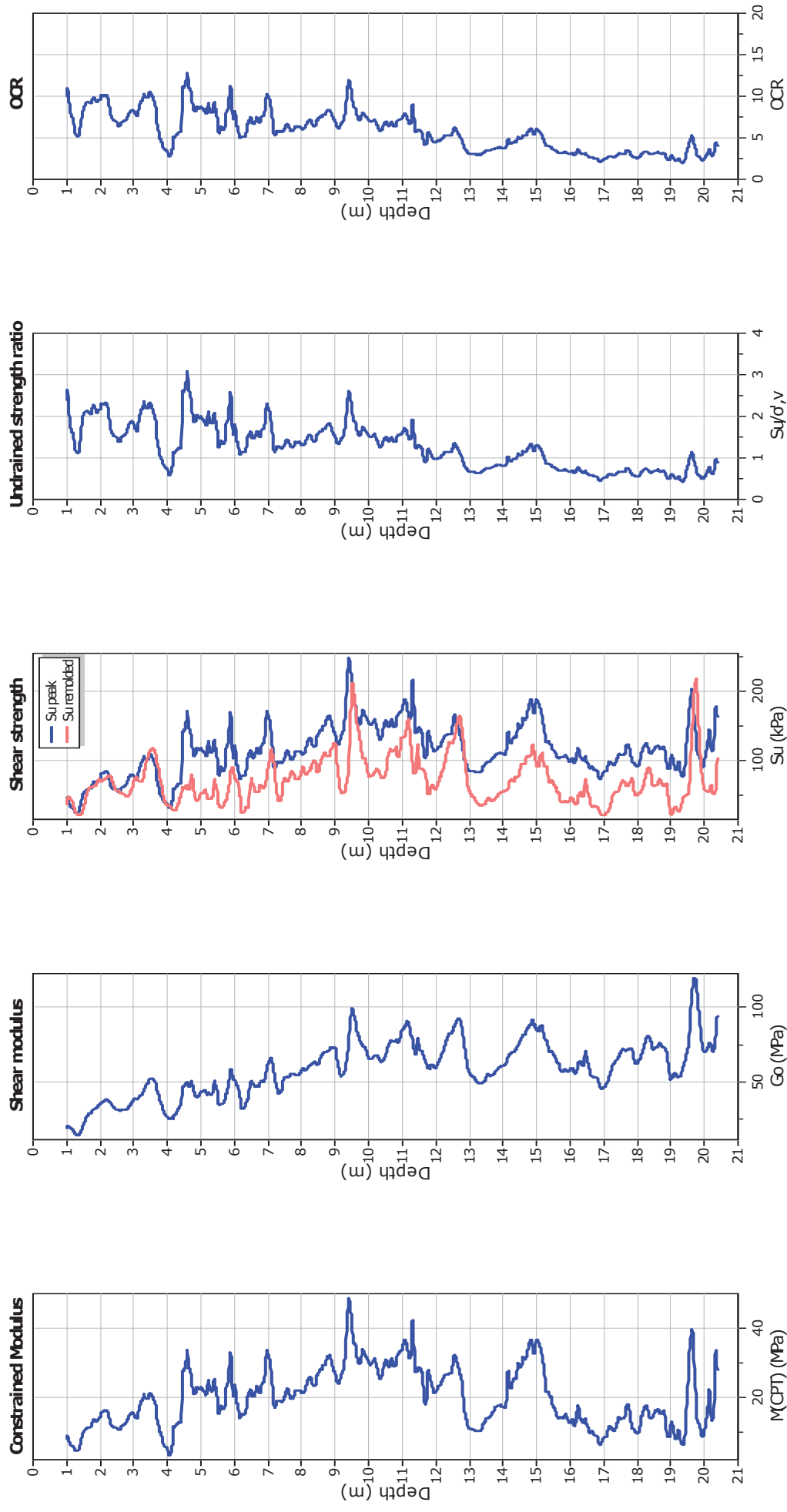
SPT N_{60} : Based on I_c and q_t

Young's modulus: Based on variable alpha using I_c (Robertson, 2009)

Relative density constant, C_{or} : 350.0

Phi: Based on Kulhawy & Mayne (1990)

—●— User defined estimation data



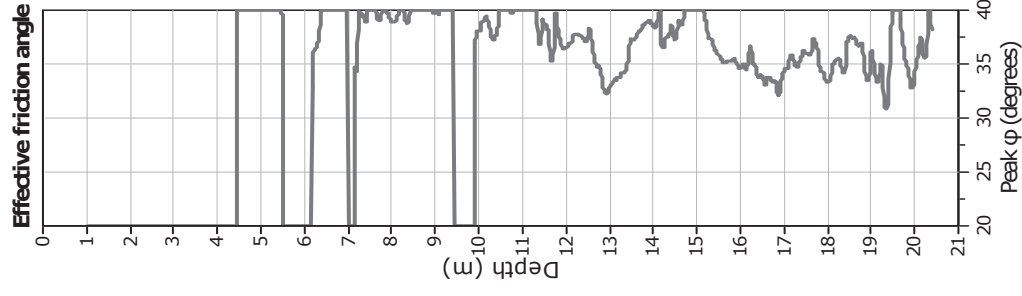
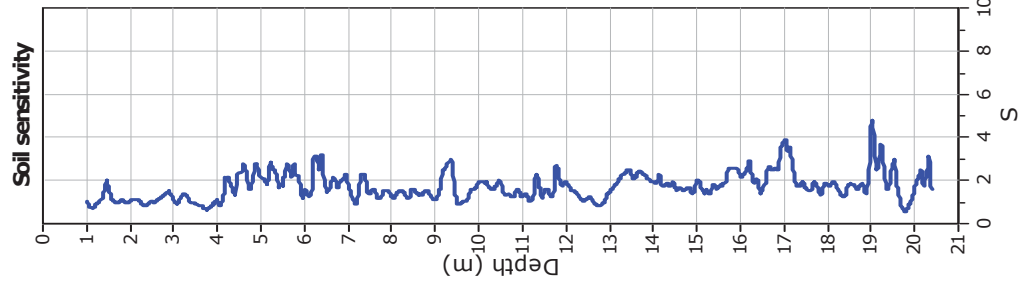
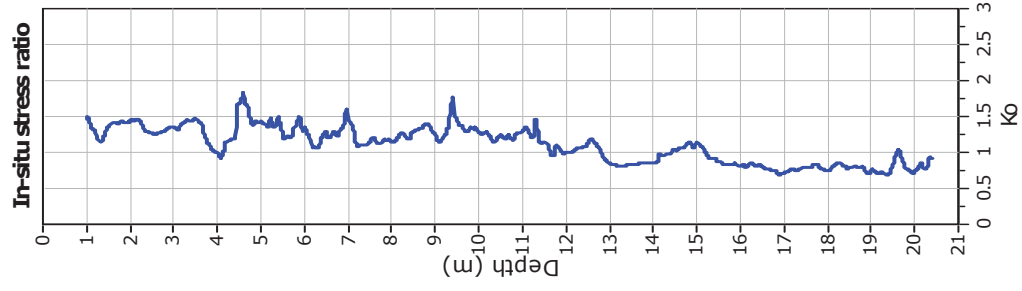
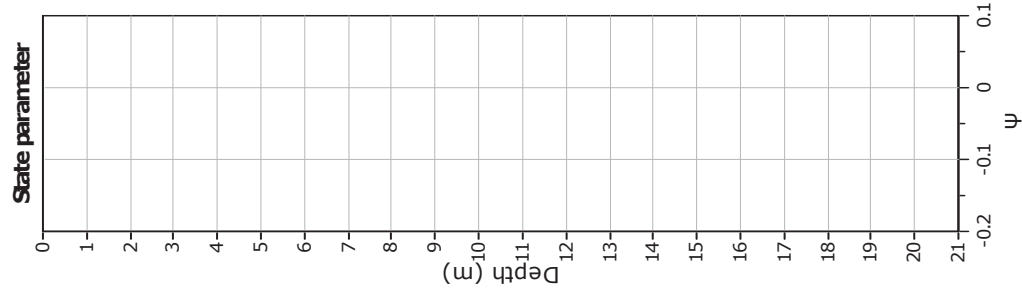
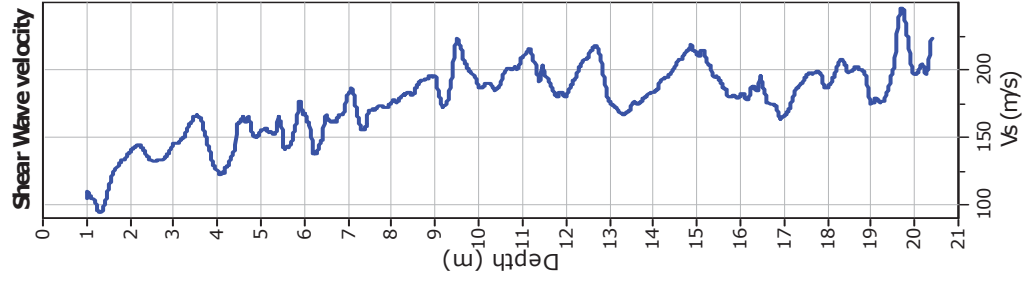
Calculation parameters

Constrained modulus: Based on variable $\alpha/\rho/\mu$ using I_c and Q_m (Robertson, 2009)
 G_o : Based on variable $\alpha/\rho/\mu$ using I_c (Robertson, 2009)

OCR factor for clays, N_{kt} : 0.33

— User defined estimation data
— Flat Dilatometer Test data

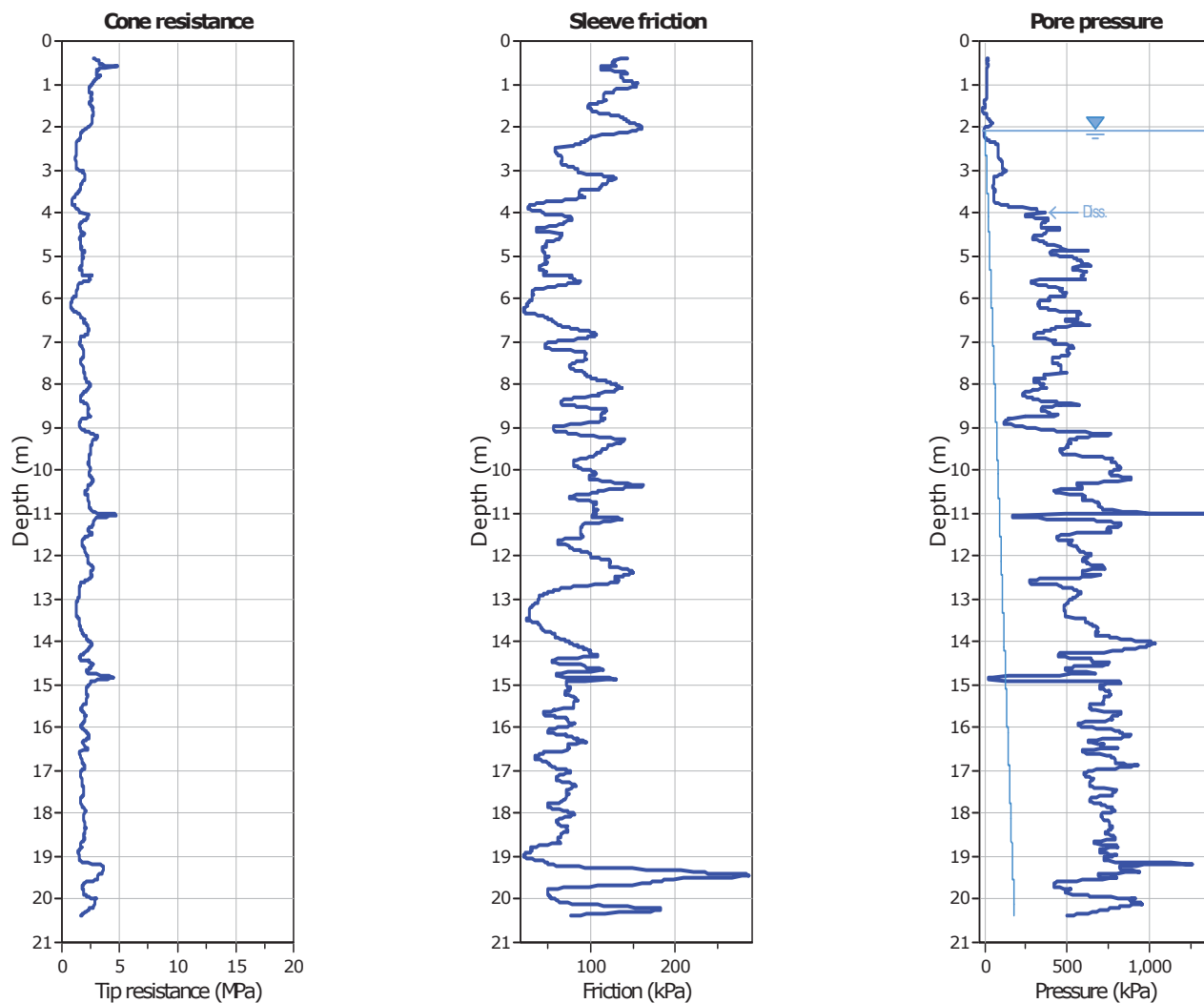
Undrained shear strength cone factor for clays, N_{kt} : 14



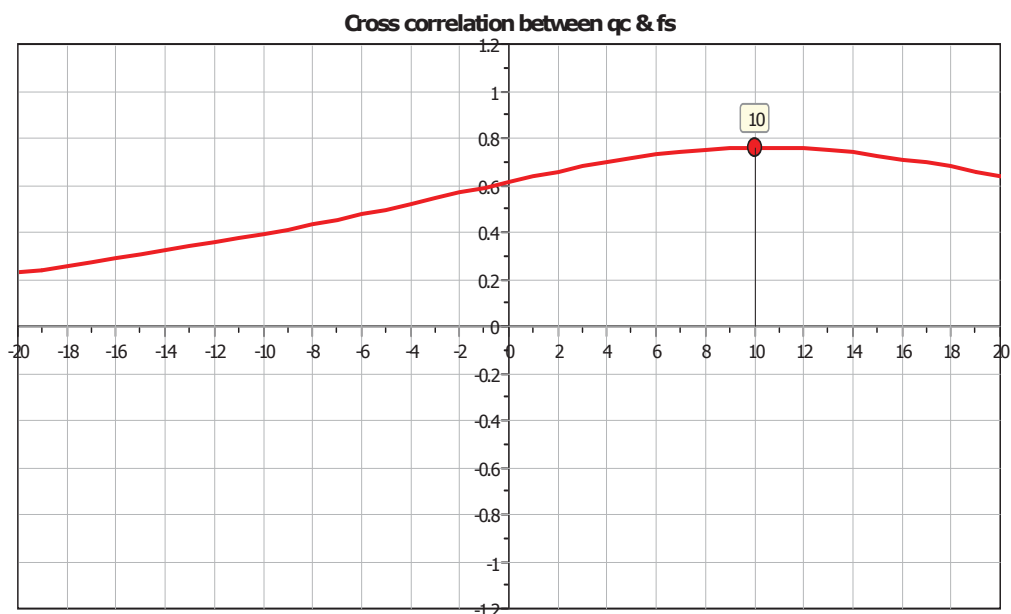
Calculation parameters

Soil Sensitivity factor, N_s : 7.00

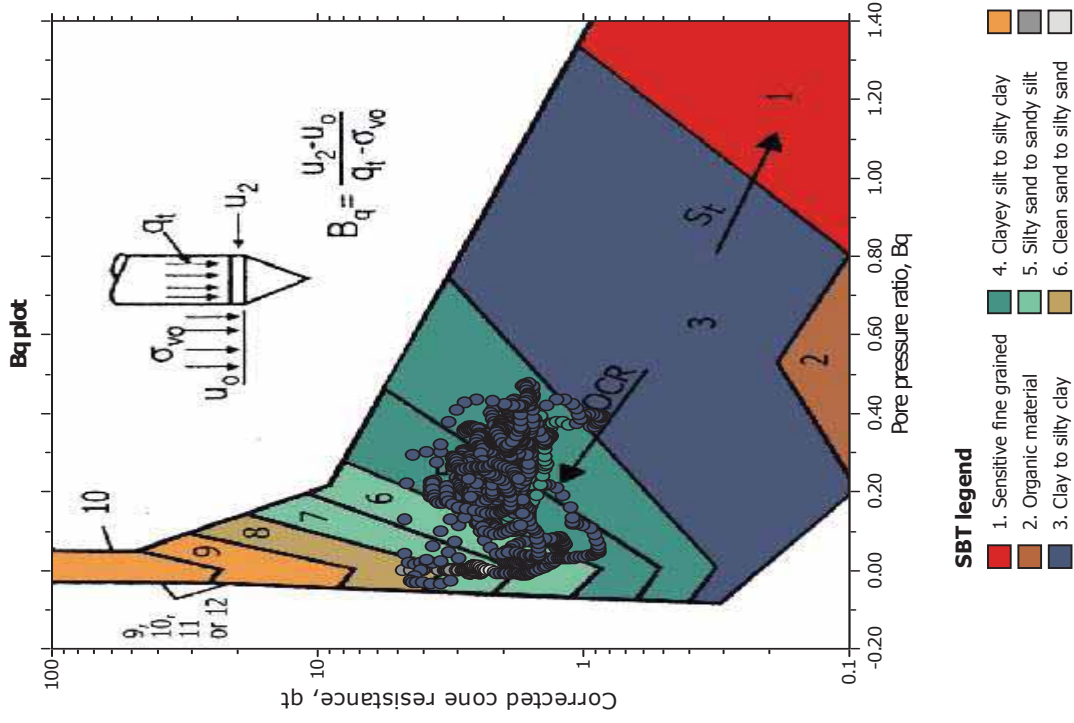
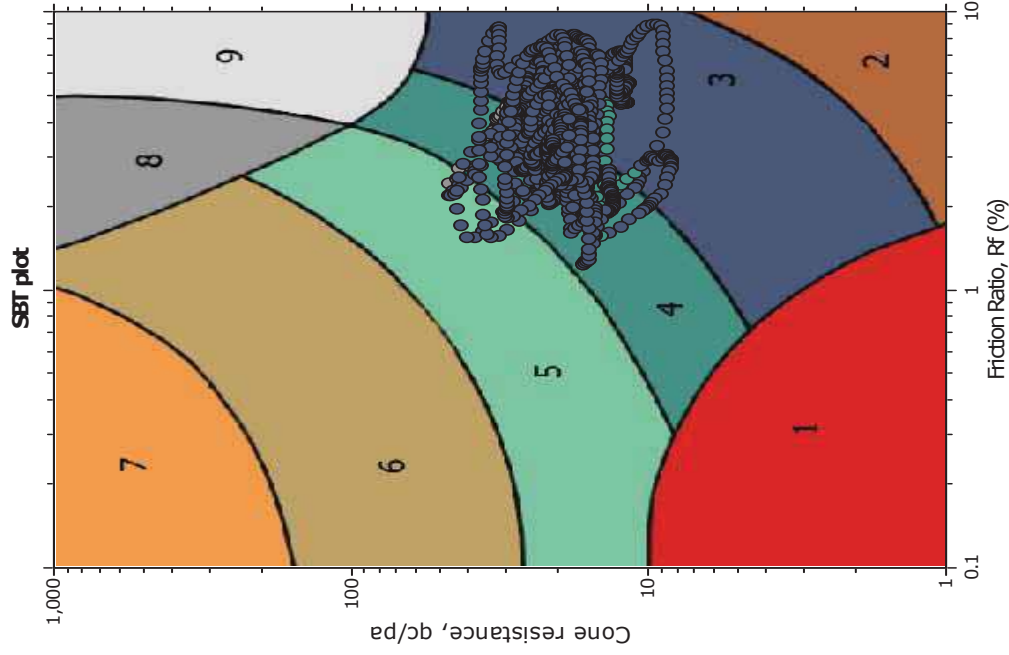
—●— User defined estimation data

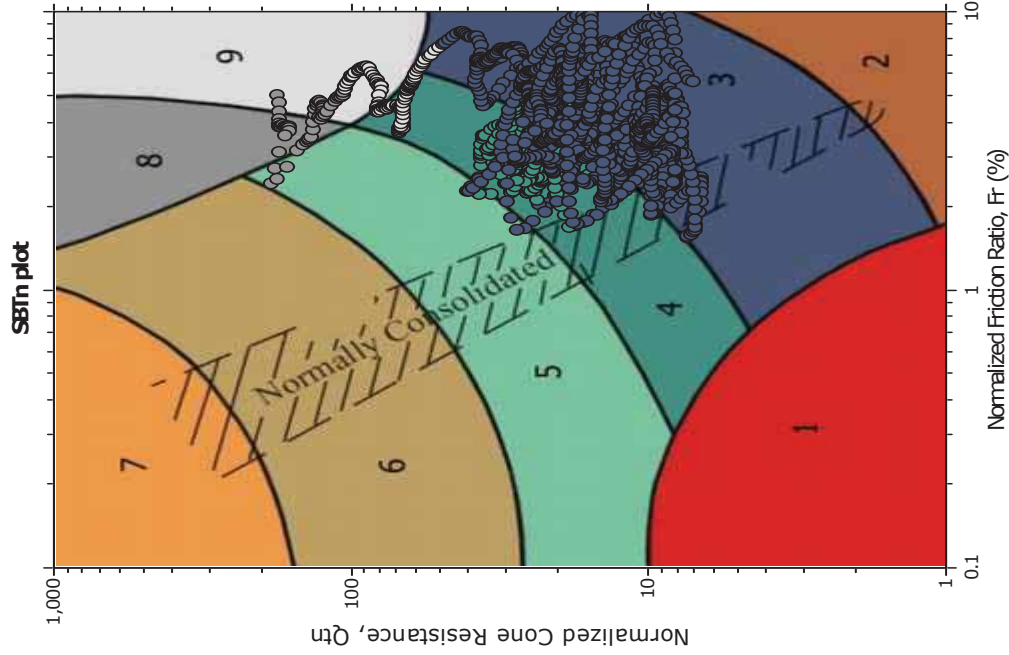


The plot below presents the cross correlation coefficient between the raw q_c and f_s values (as measured on the field). X axes presents the lag distance (one lag is the distance between two successive CPT measurements).

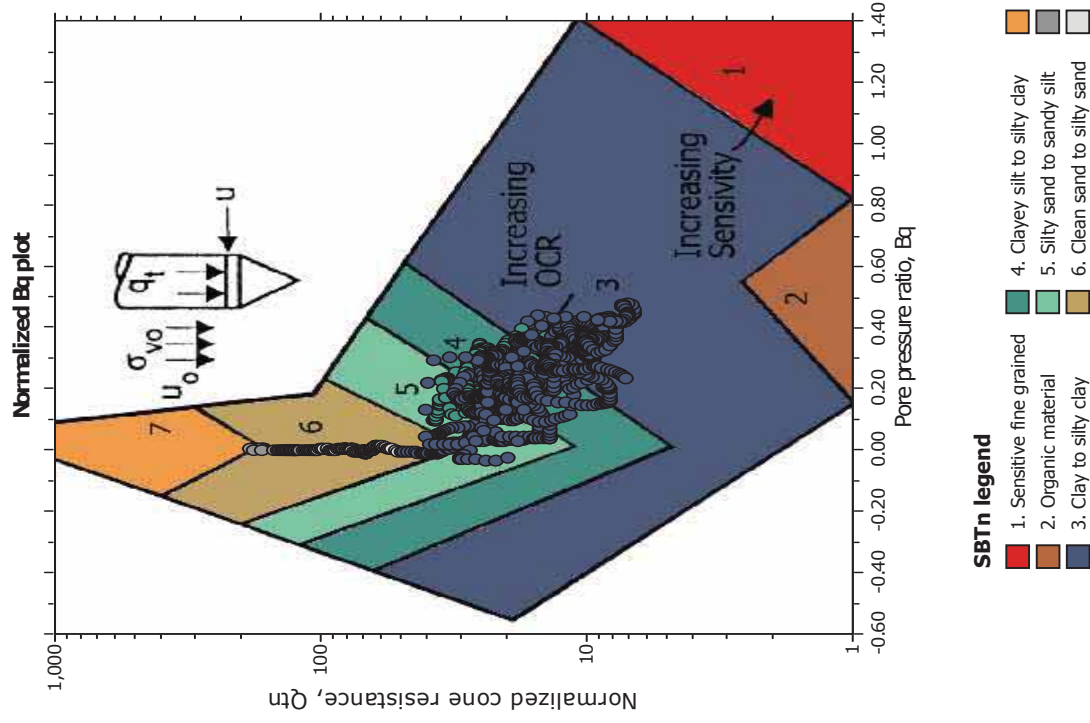


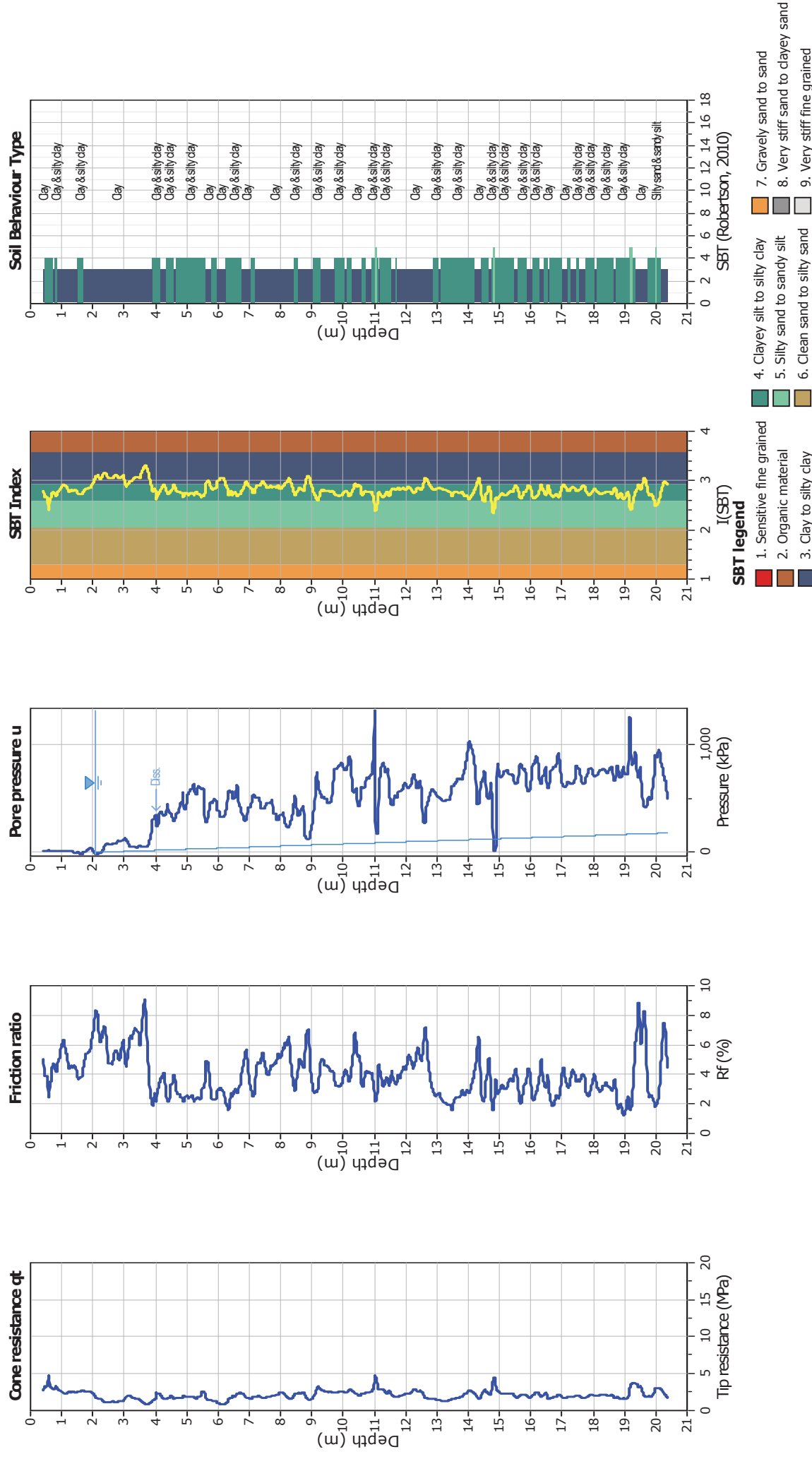
SBT - Bq plots





SBT - Bq plots (normalized)



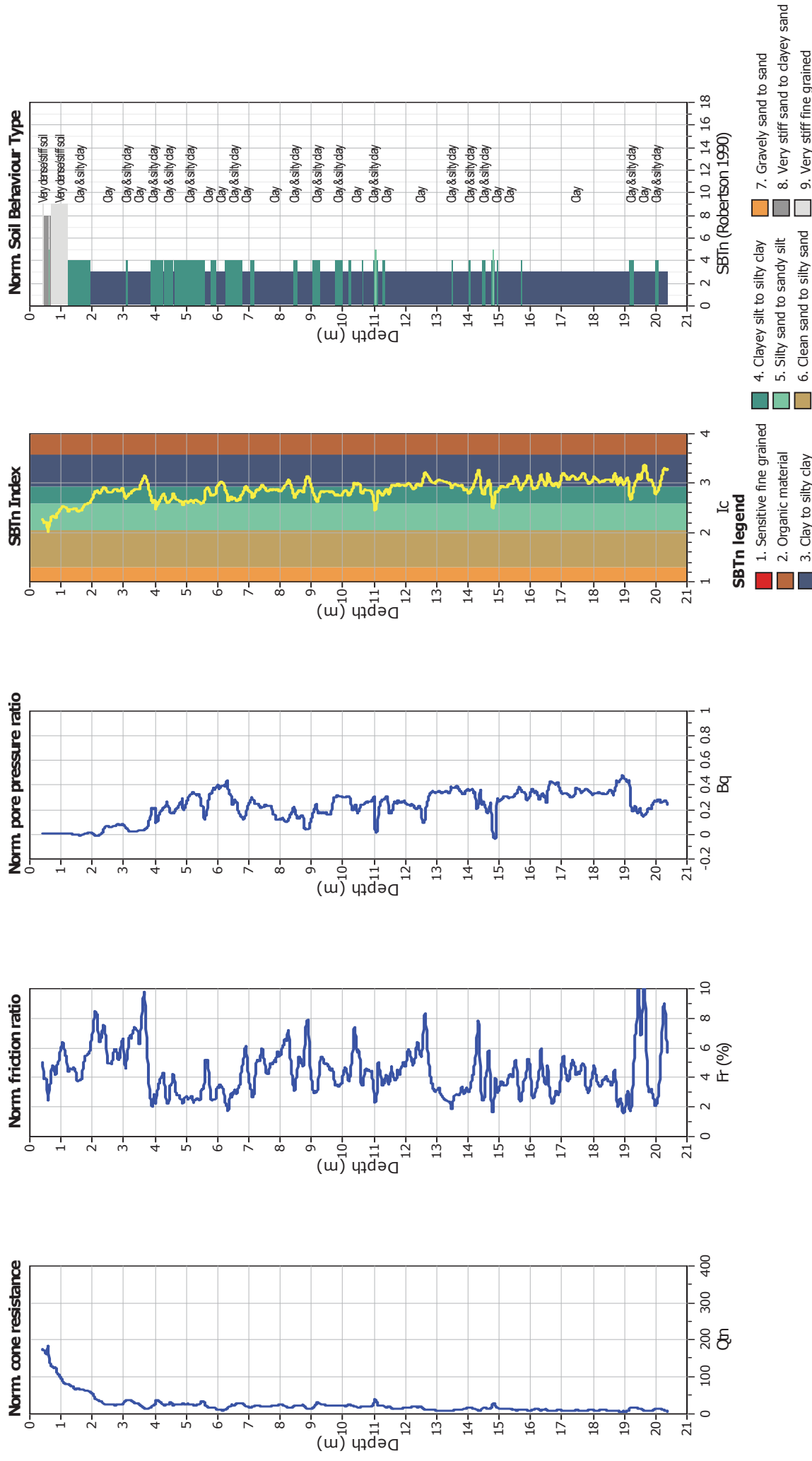


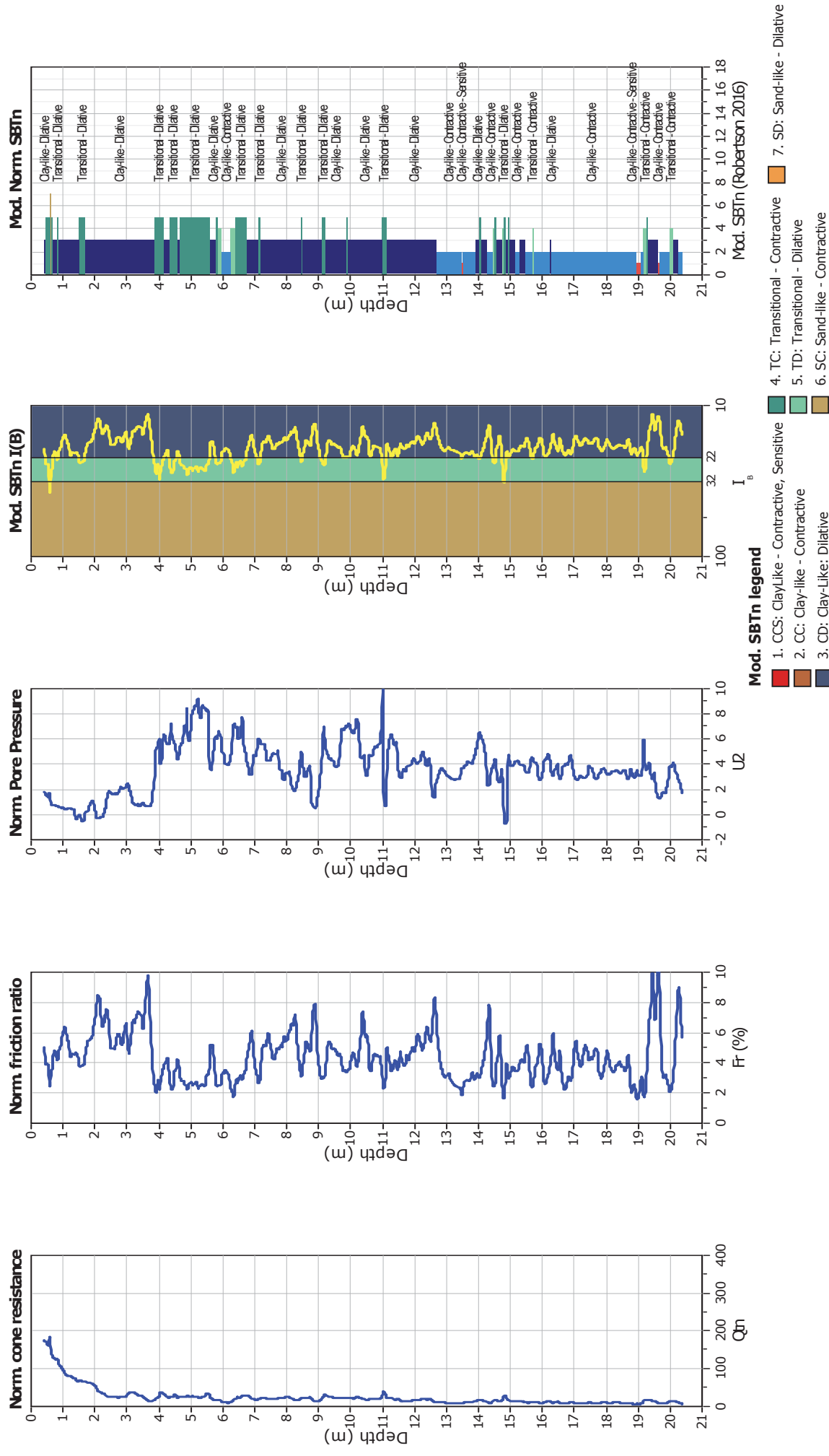


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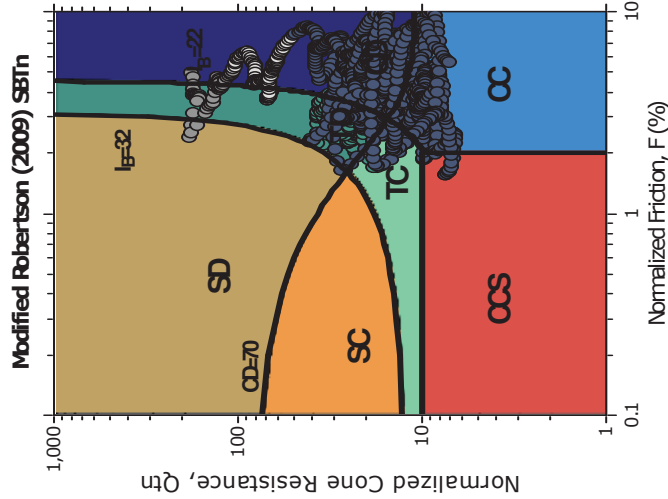
Project: Studio del terreno di fondazione
Location: Fossoli, AIMAG

CPT: CPTU4
Total depth: 20.39 m, Date: 29/10/2021

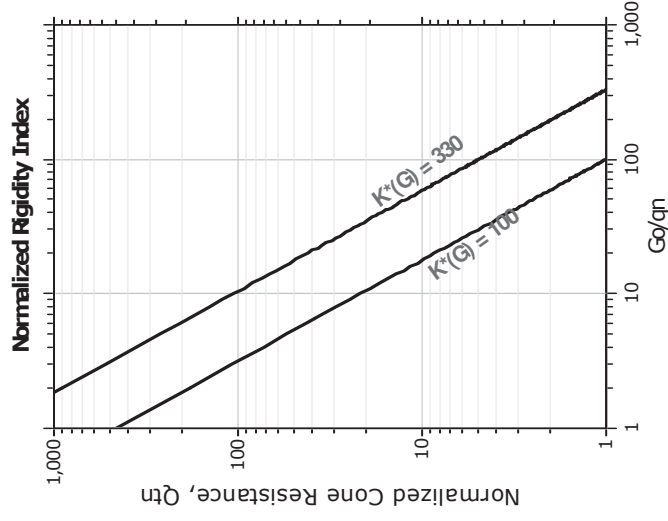
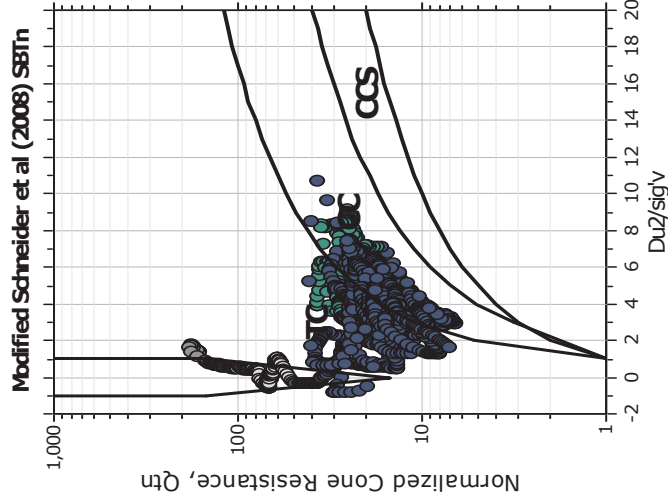




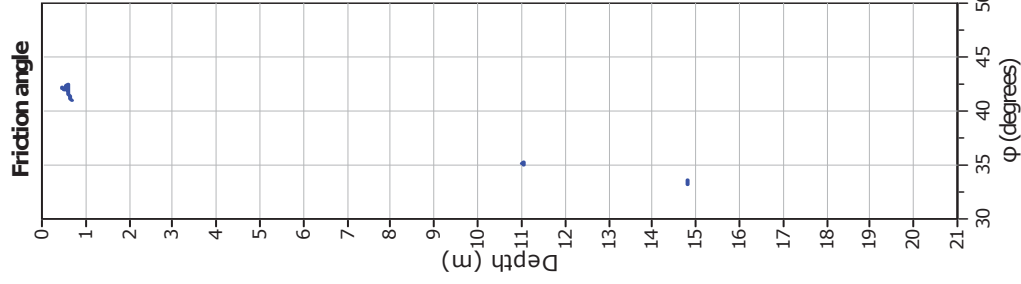
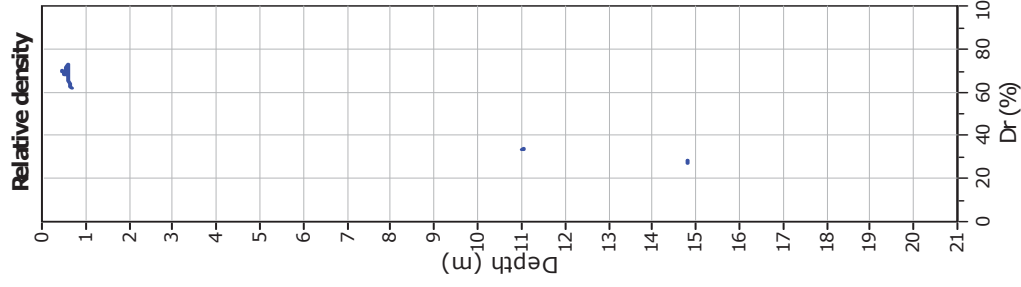
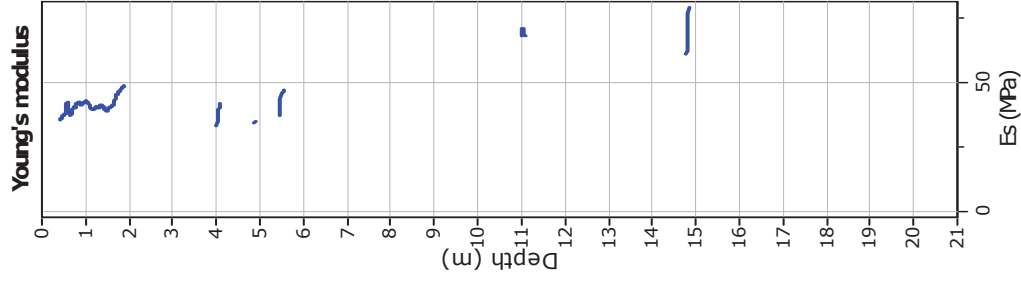
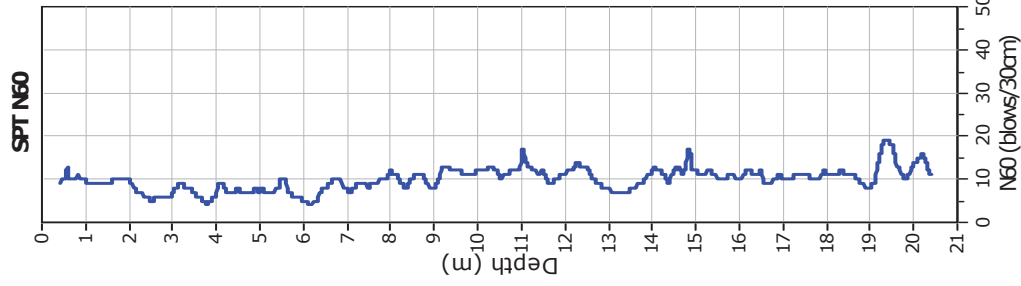
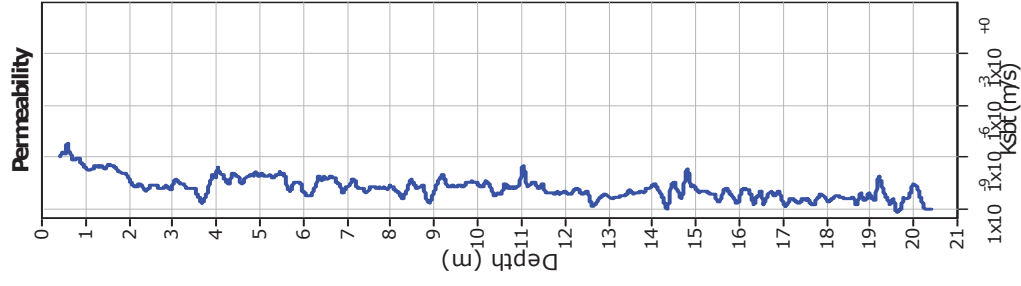
Updated SBTn plots



CCS: Clay-like - Contractive - Sensitive
CC: Clay-like - Contractive
CD: Clay-like - Dilative
TC: Transitional - Contractive
TD: Transitional - Dilative
SC: Sand-like - Contractive
SD: Sand-like - Dilative



$K(G) > 330$: Soils with significant microstructure
(e.g. age/cementation)



Calculation parameters

Permeability: Based on SBT_n

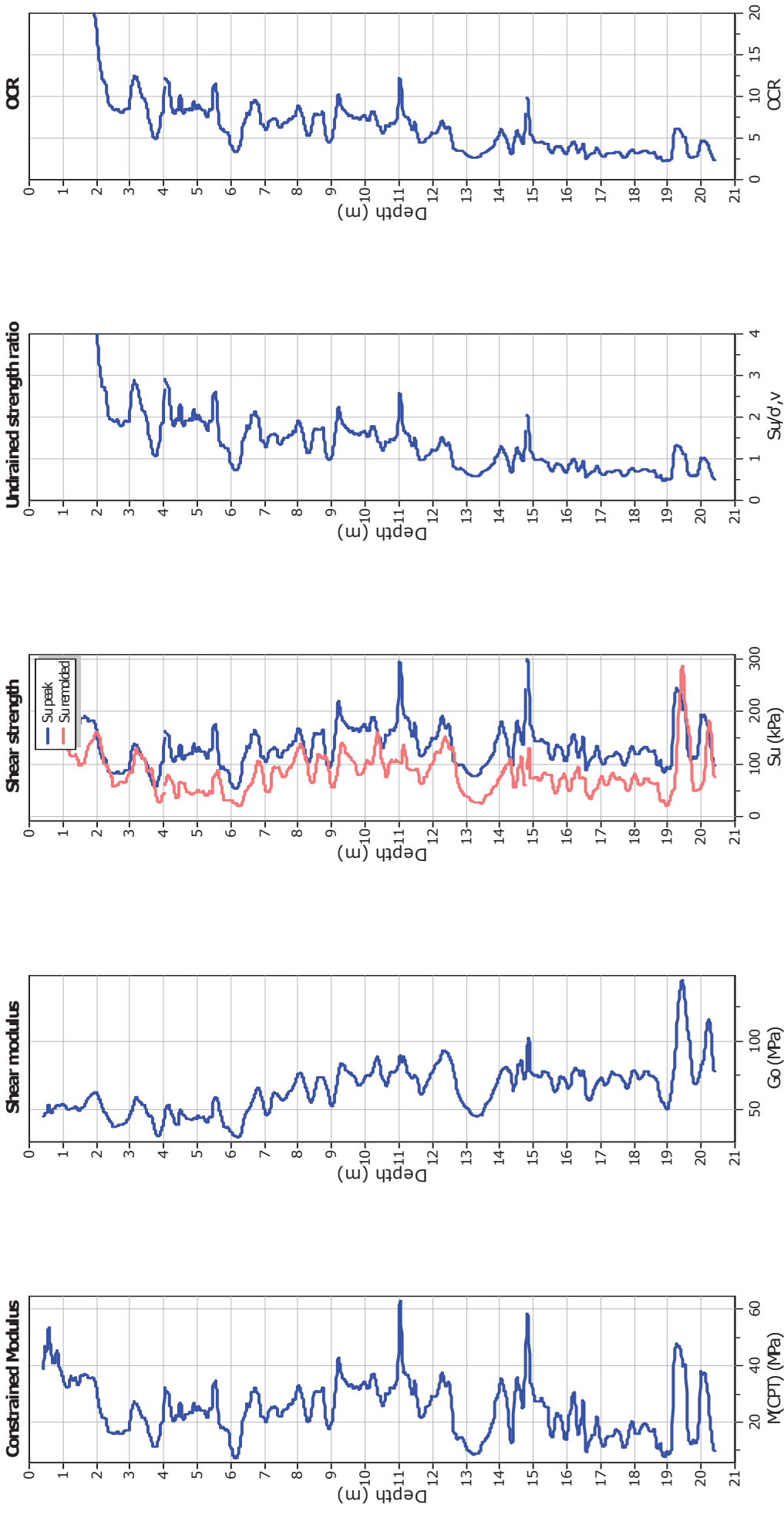
SPT N_{60} : Based on I_c and q_t

Young's modulus: Based on variable alpha using I_c (Robertson, 2009)

Relative density constant, C_{or} : 350.0

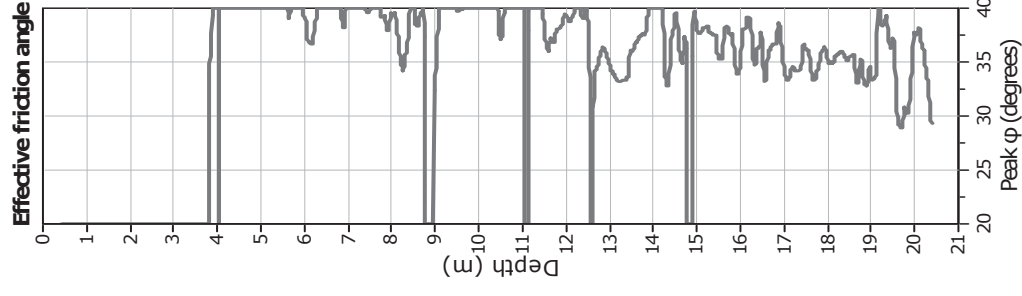
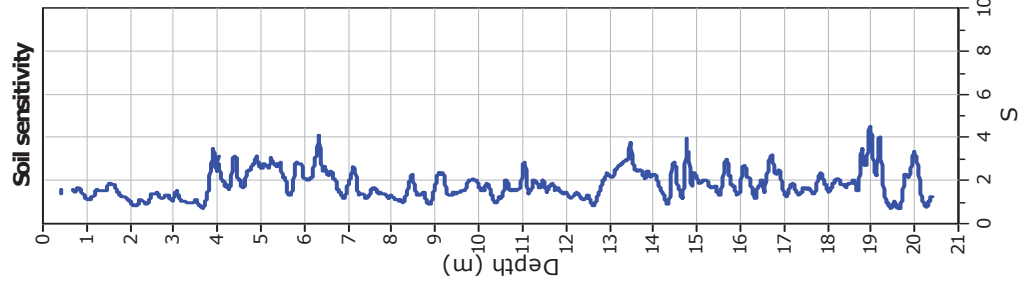
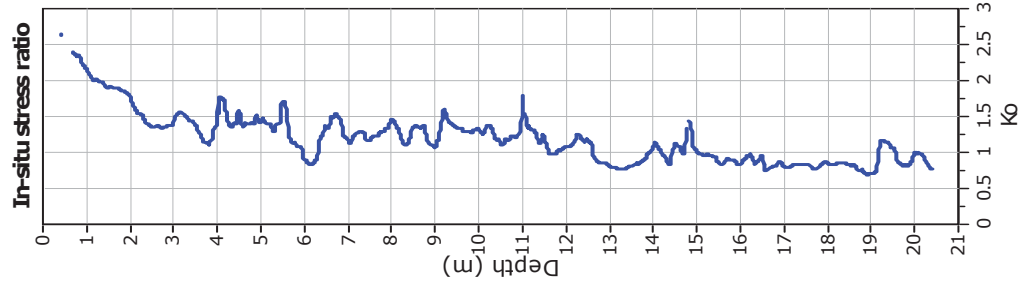
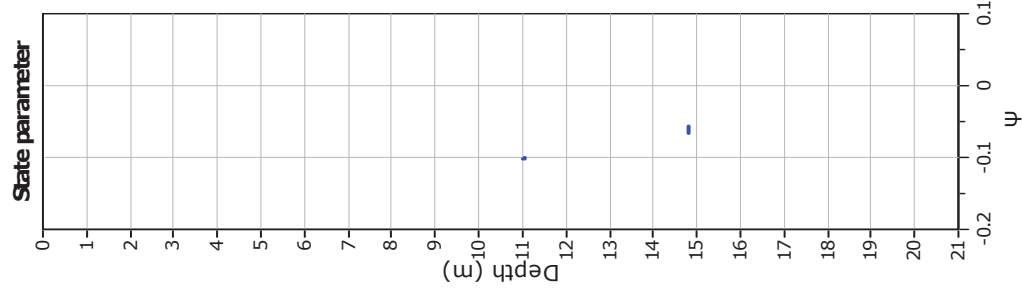
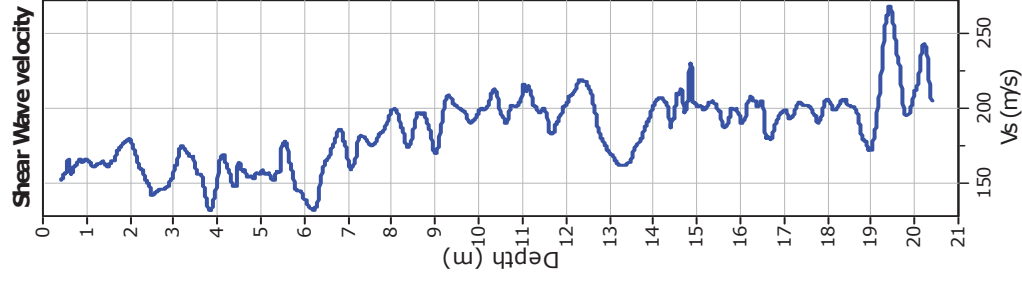
Phi: Based on Kulhawy & Mayne (1990)

—●— User defined estimation data



Calculation parameters

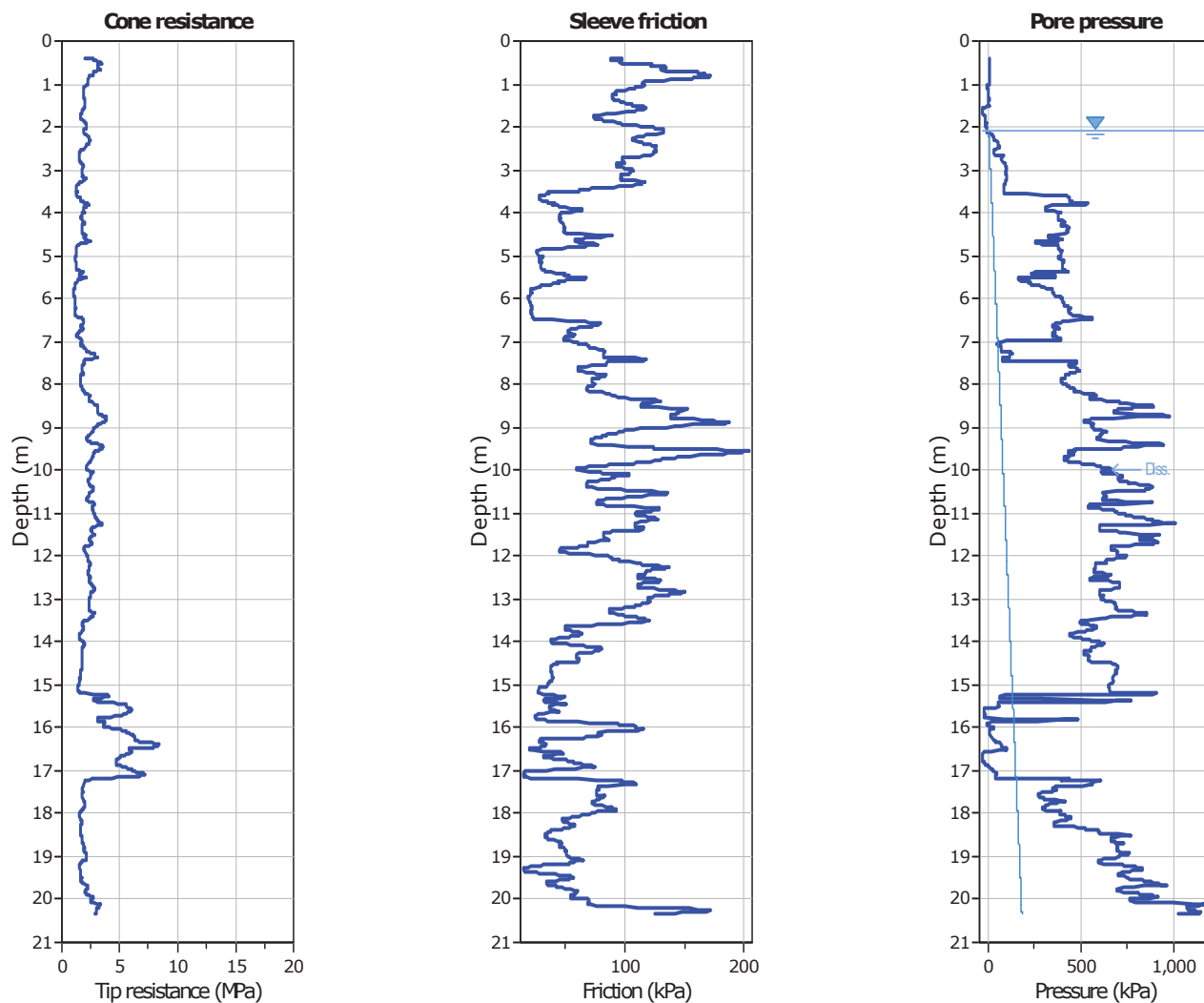
Constrained modulus: Based on variable $\alpha/\rho/\lambda$ using I_c and Q_m (Robertson, 2009) OCR factor for clays, N_{kt} : 0.33
 G_o : Based on variable $\alpha/\rho/\lambda$ using I_c (Robertson, 2009) —●— User defined estimation data
Undrained shear strength cone factor for clays, N_{kt} : 14 —●— Flat Dilatometer Test data



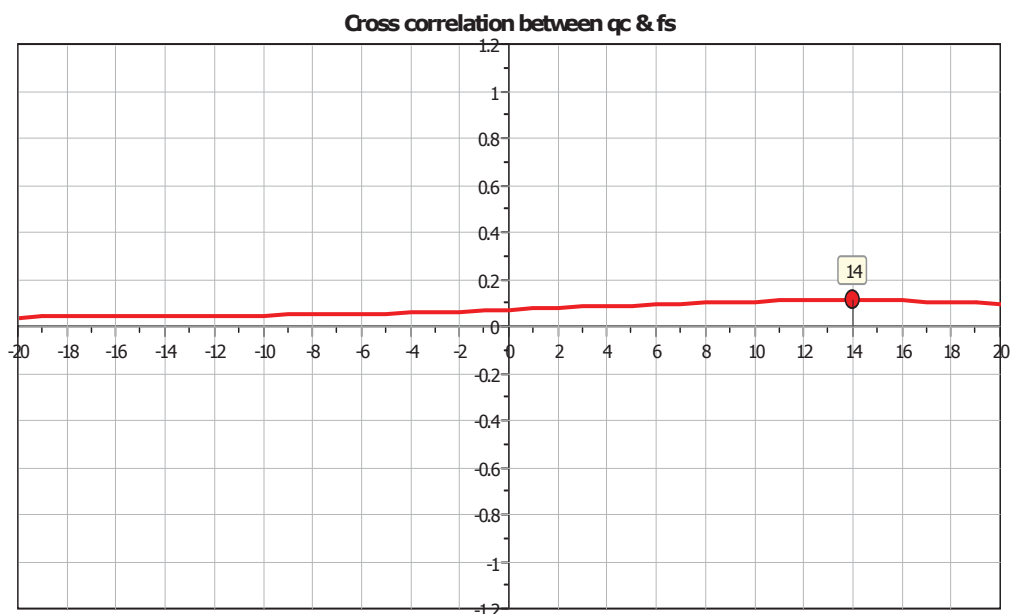
Calculation parameters

Soil Sensitivity factor, N_s : 7.00

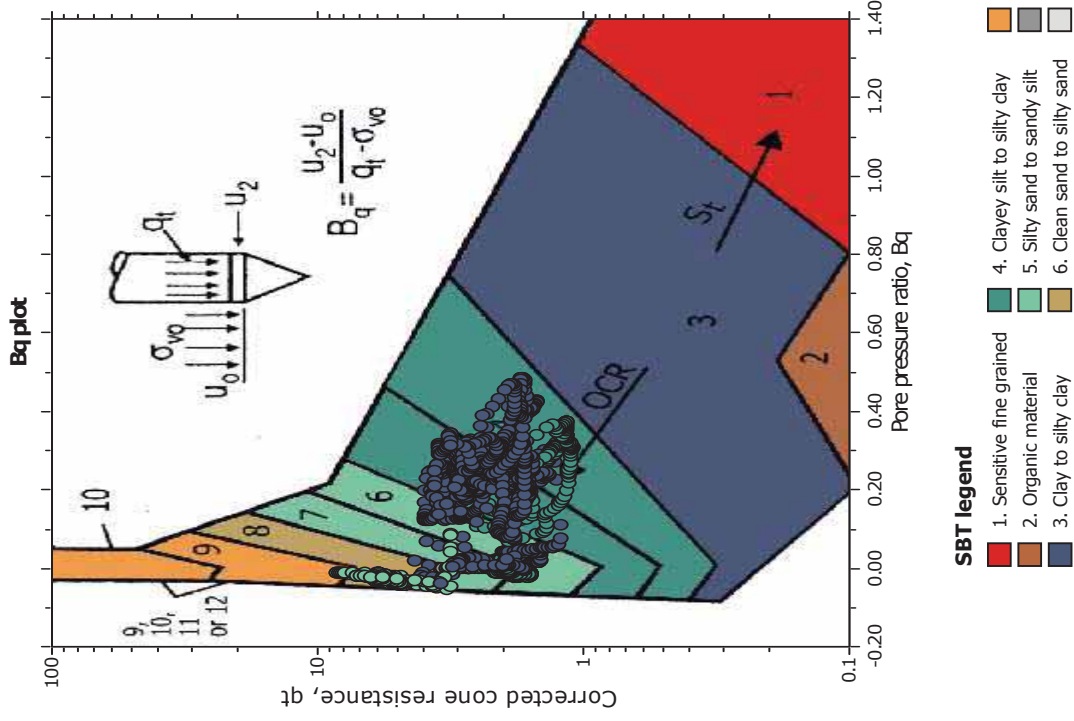
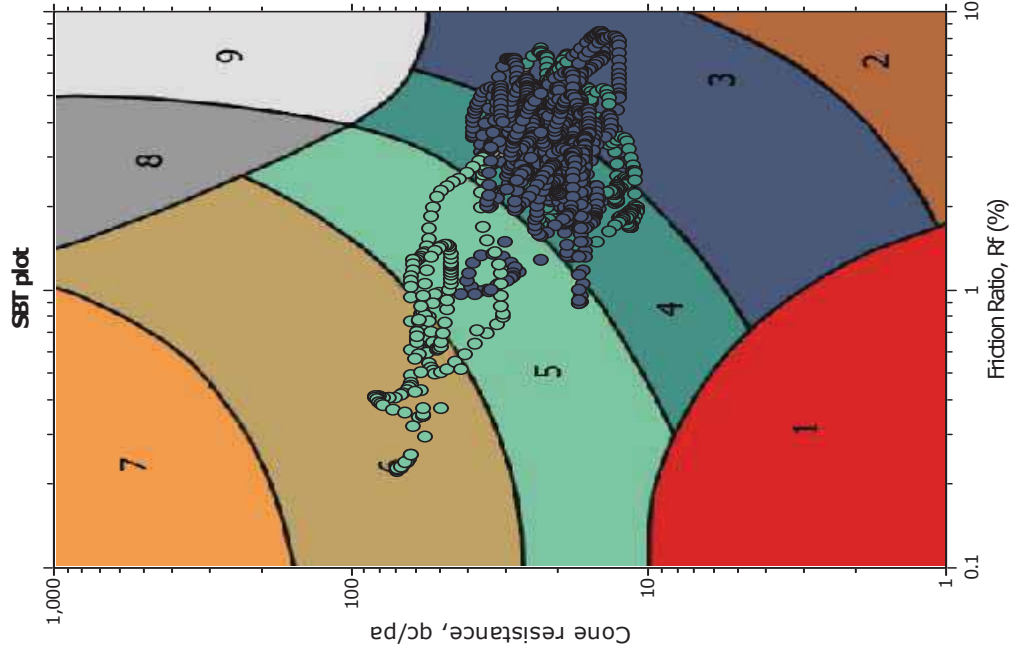
—●— User defined estimation data

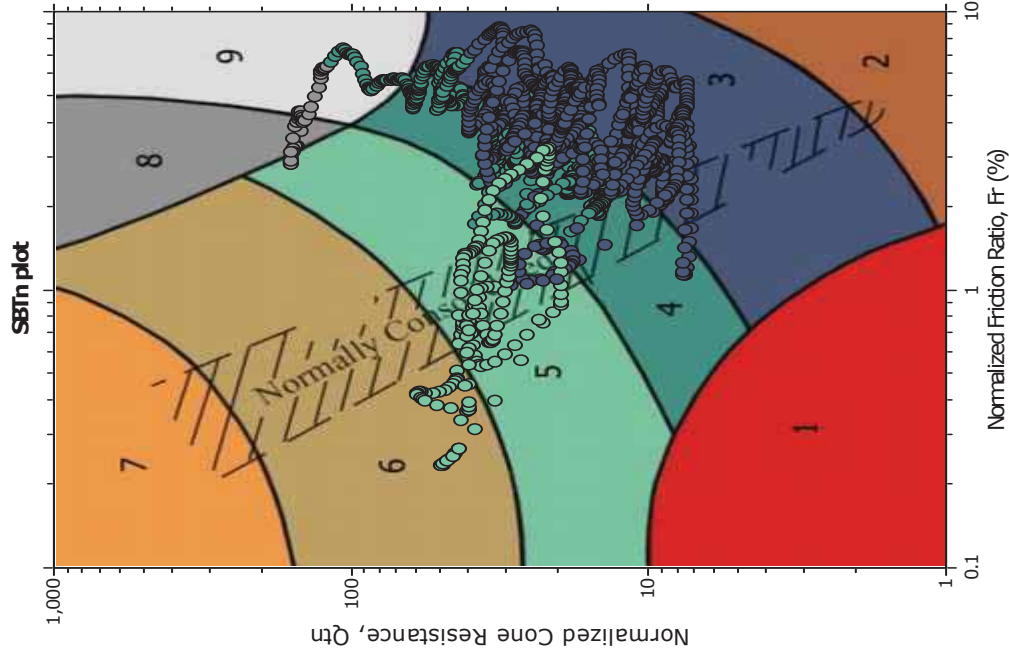


The plot below presents the cross correlation coefficient between the raw q_c and f_s values (as measured on the field). X axes presents the lag distance (one lag is the distance between two successive CPT measurements).

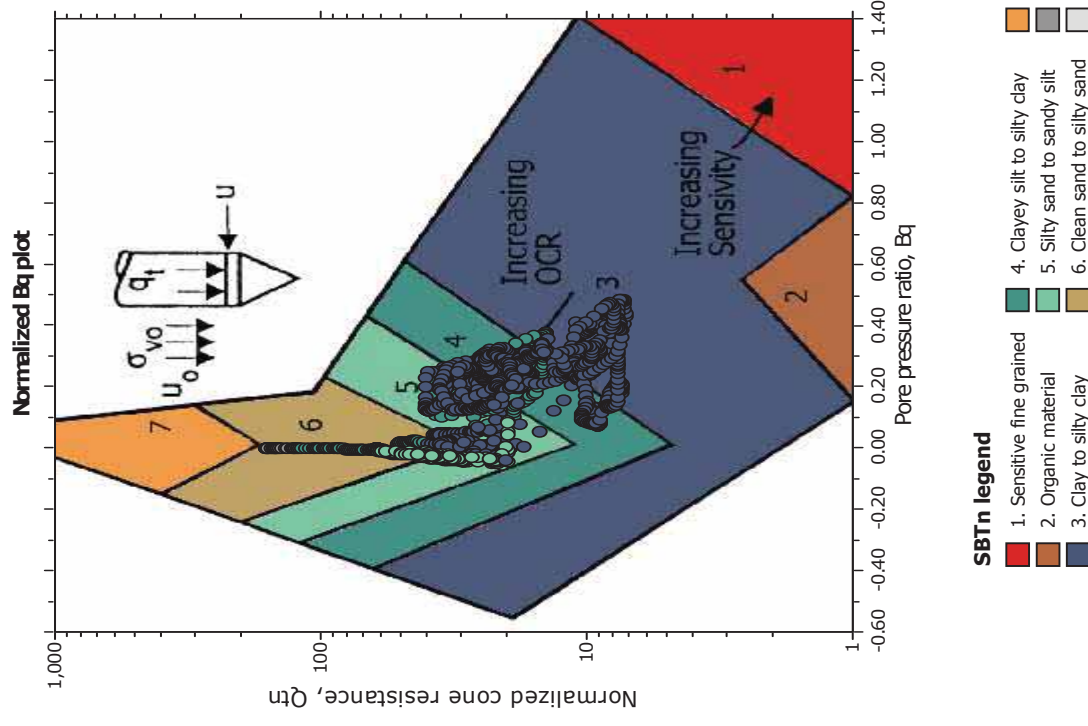


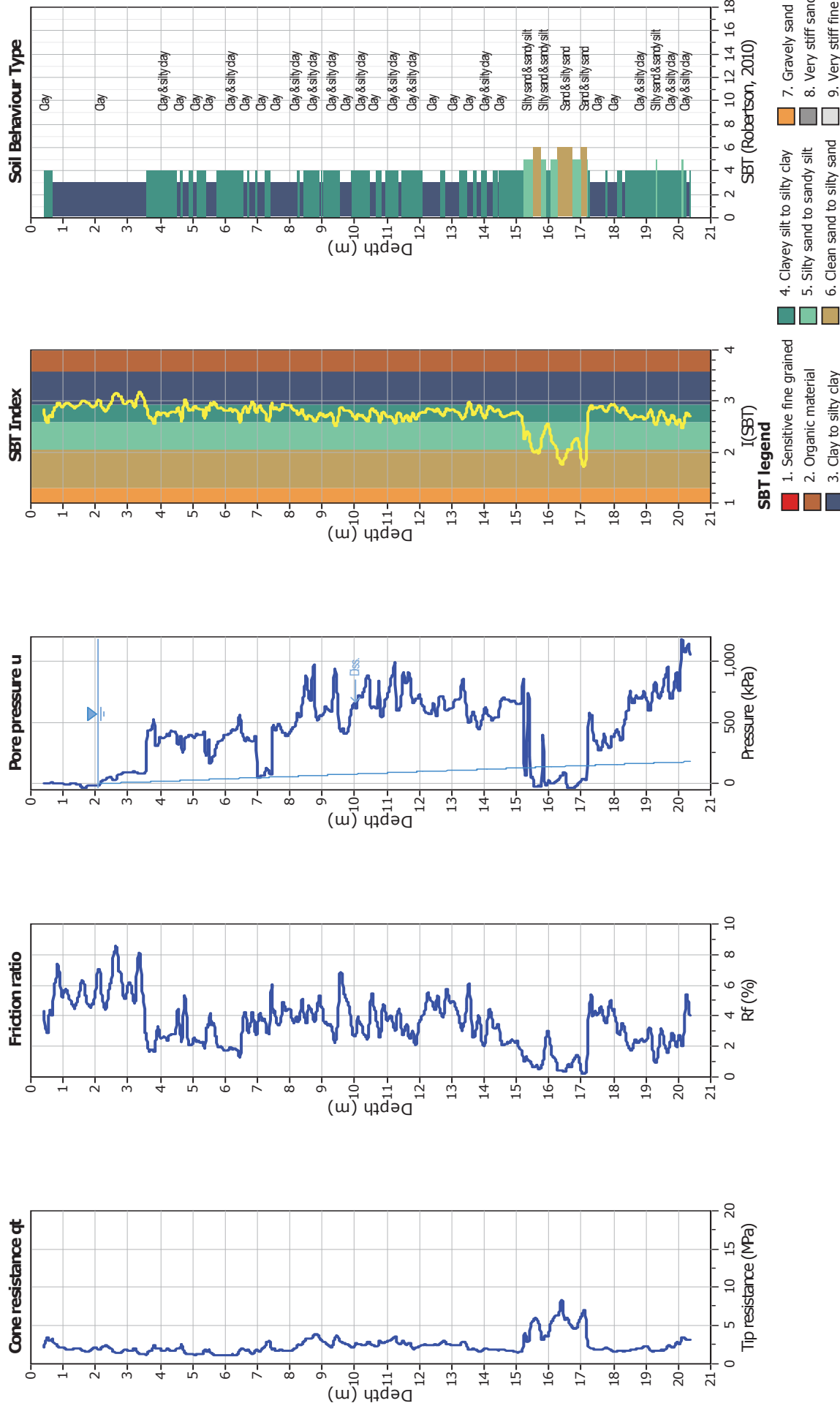
SBT - Bq plots





SBT - Bq plots (normalized)



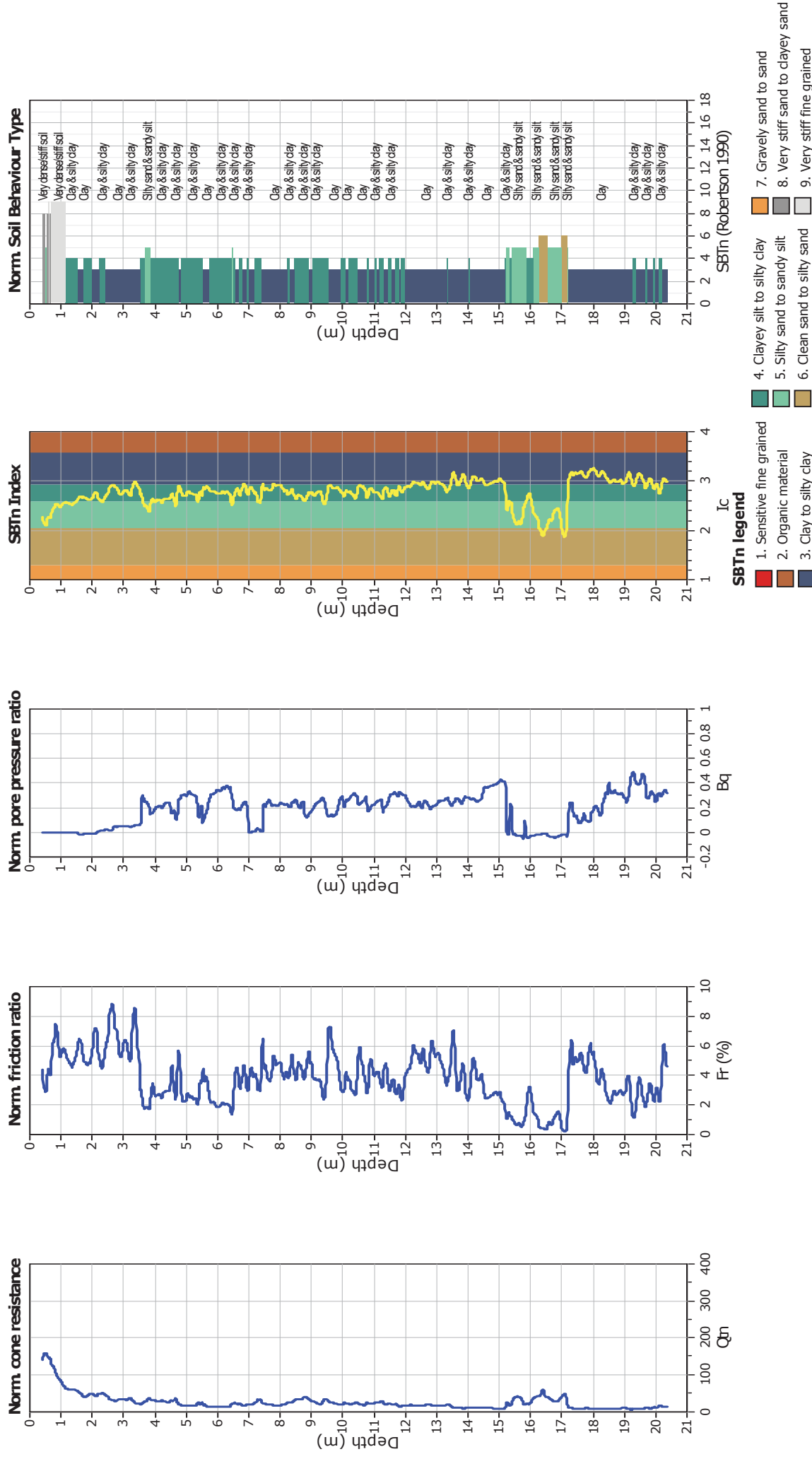


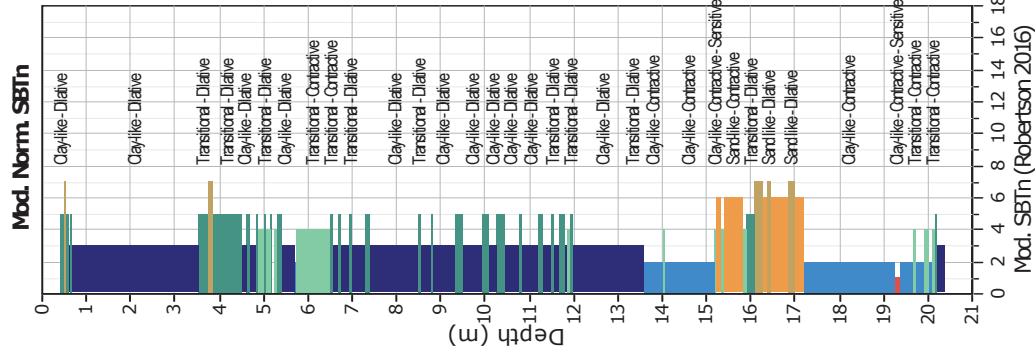
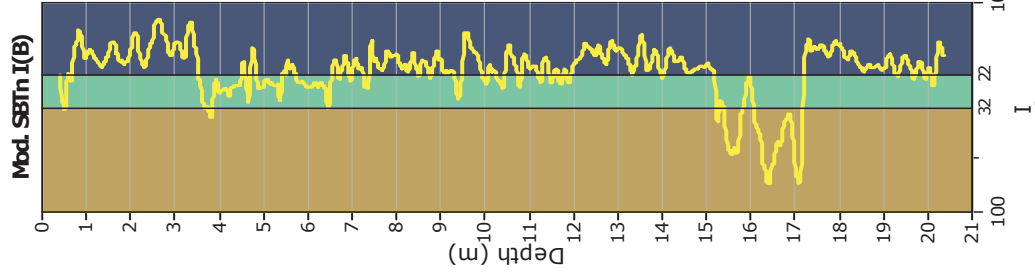
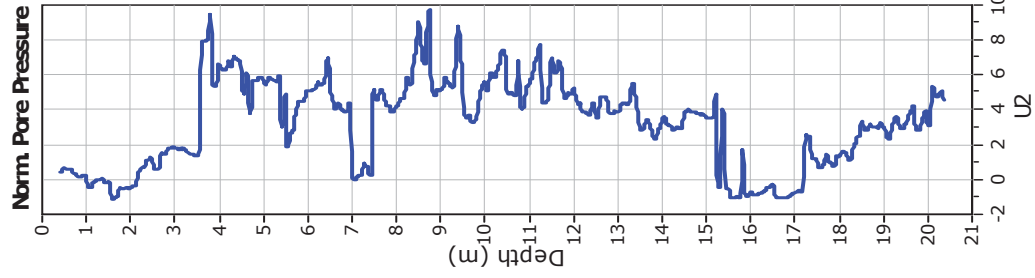
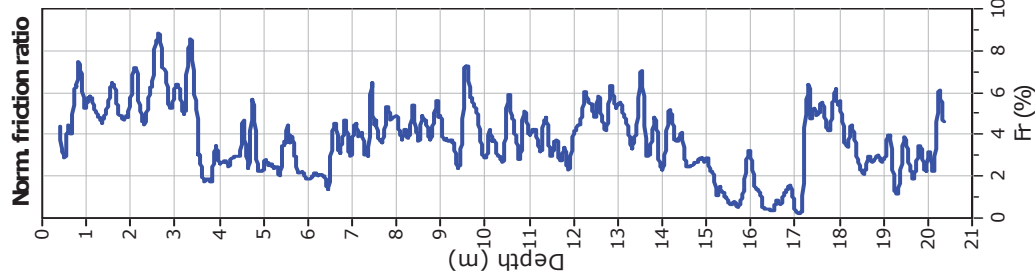
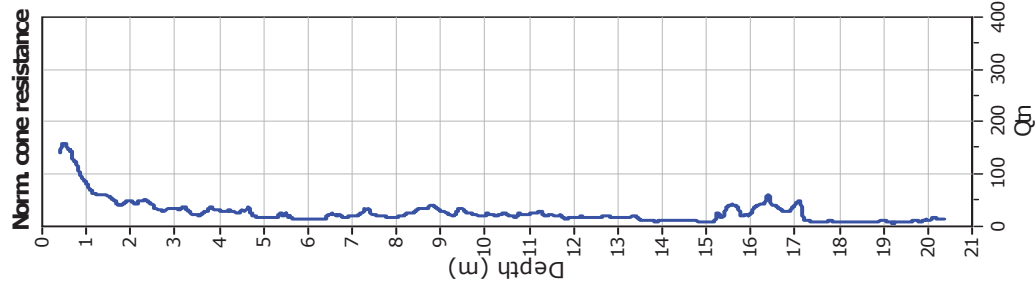


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Project: Studio del terreno di fondazione
Location: Fossoli, AIMAG

CPT: CPTU5
Total depth: 20.35 m, Date: 29/10/2021

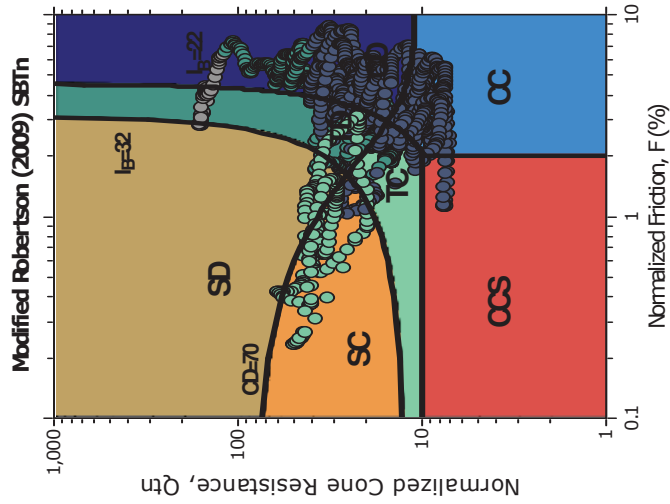




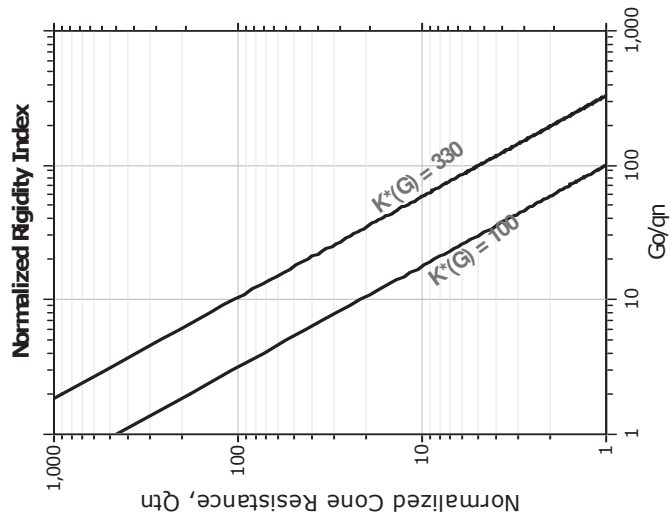
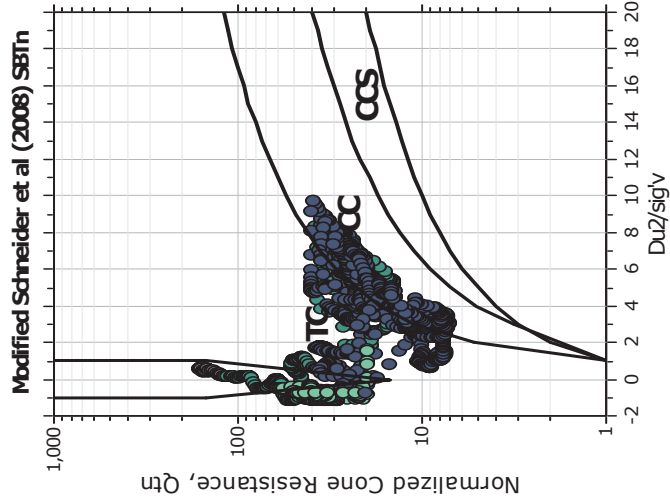
Mod. SBTn legend

- 1. CCS: ClayLike - Contractive, Sensitive
- 2. CC: Clay-like - Contractive
- 3. CD: Clay-Like: Dilative
- 4. TC: Transitional - Contractive
- 5. TD: Transitional - Dilative
- 6. SC: Sand-like - Contractive
- 7. SD: Sand-like - Dilative

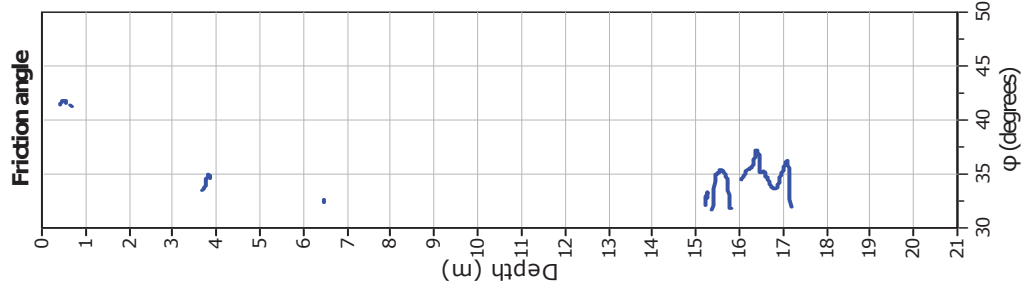
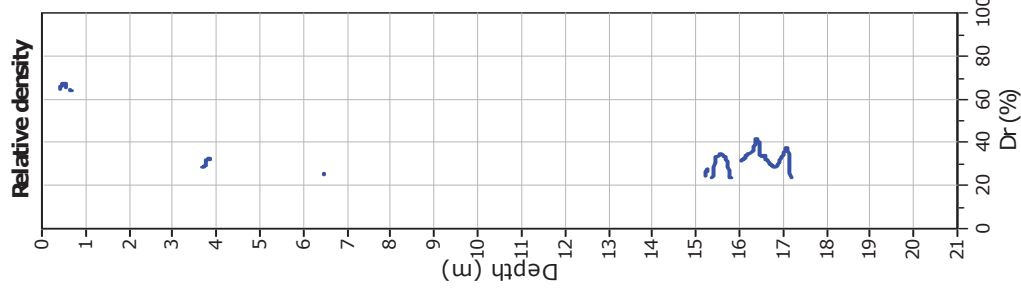
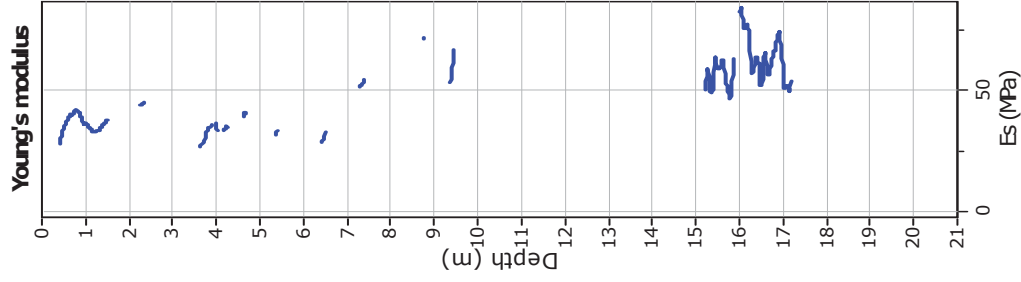
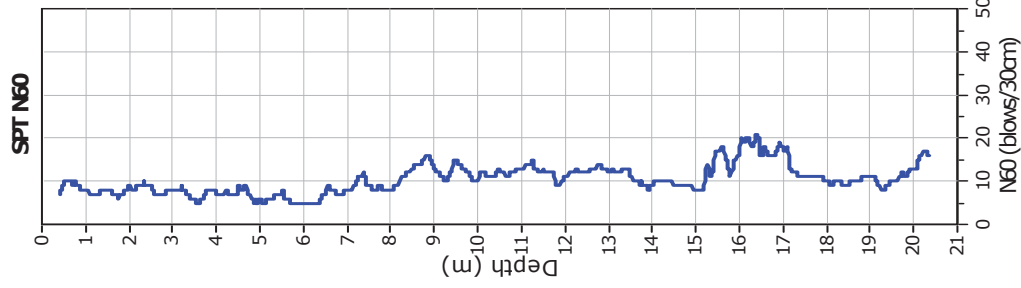
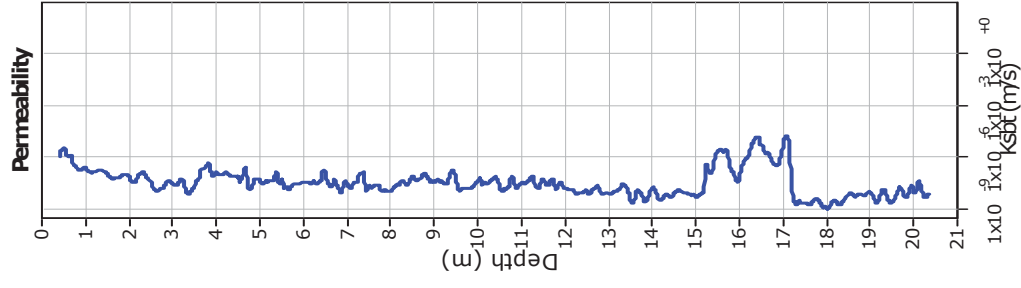
Updated SBTn plots



CCS: Clay-like - Contractive - Sensitive
CC: Clay-like - Contractive
CD: Clay-like - Dilative
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SD: Sand-like - Dilative



$K(G) > 330$: Soils with significant microstructure
(e.g. age/cementation)



Calculation parameters

Permeability: Based on SBT_n

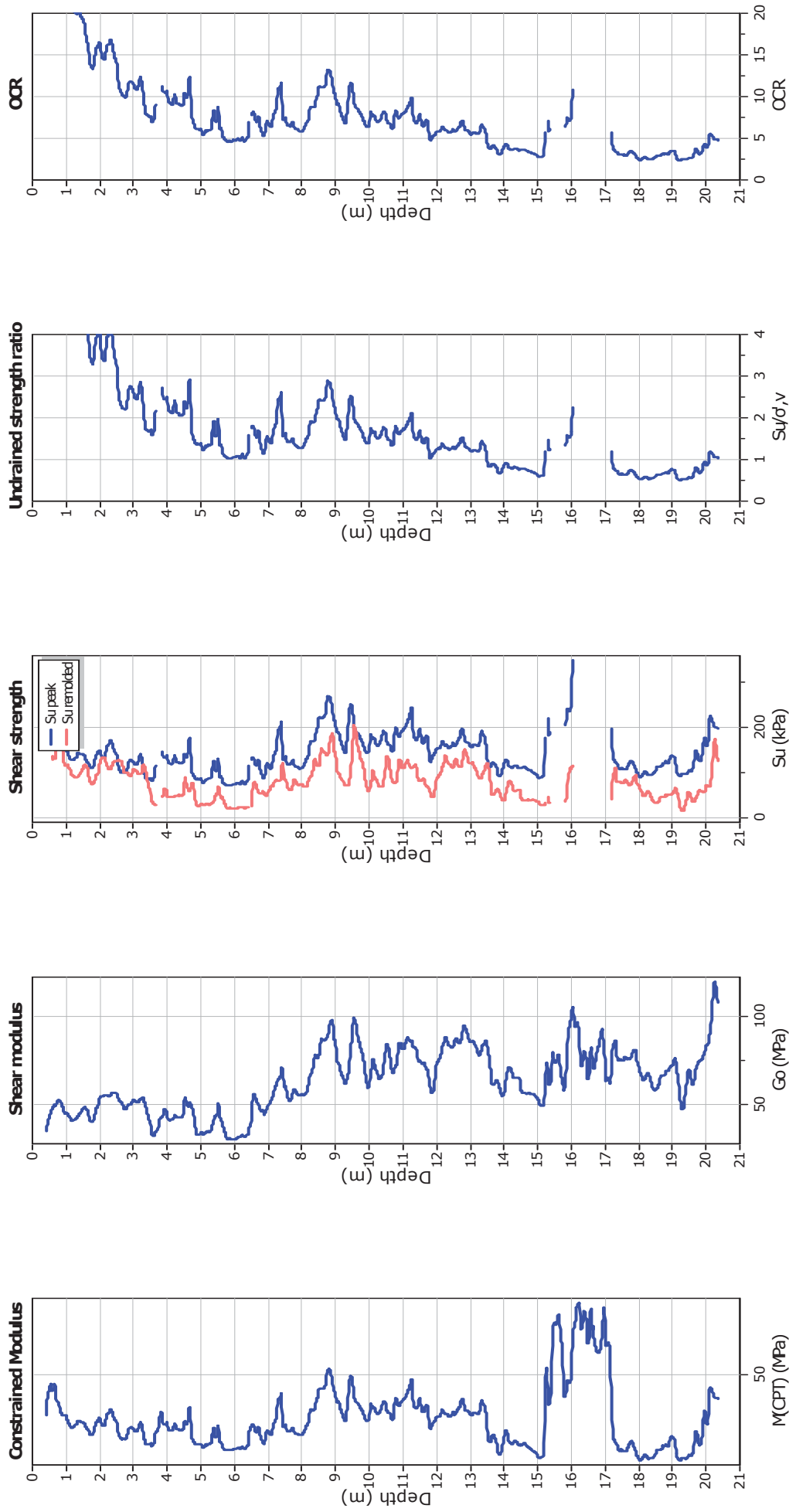
SPT N_{60} : Based on I_c and q_t

Young's modulus: Based on variable alpha using I_c (Robertson, 2009)

Relative density constant, C_{or} : 350.0

Phi: Based on Kulhawy & Mayne (1990)

—●— User defined estimation data



Calculation parameters

Constrained modulus: Based on variable $\alpha/\rho/\mu$ using I_c and Q_m (Robertson, 2009)

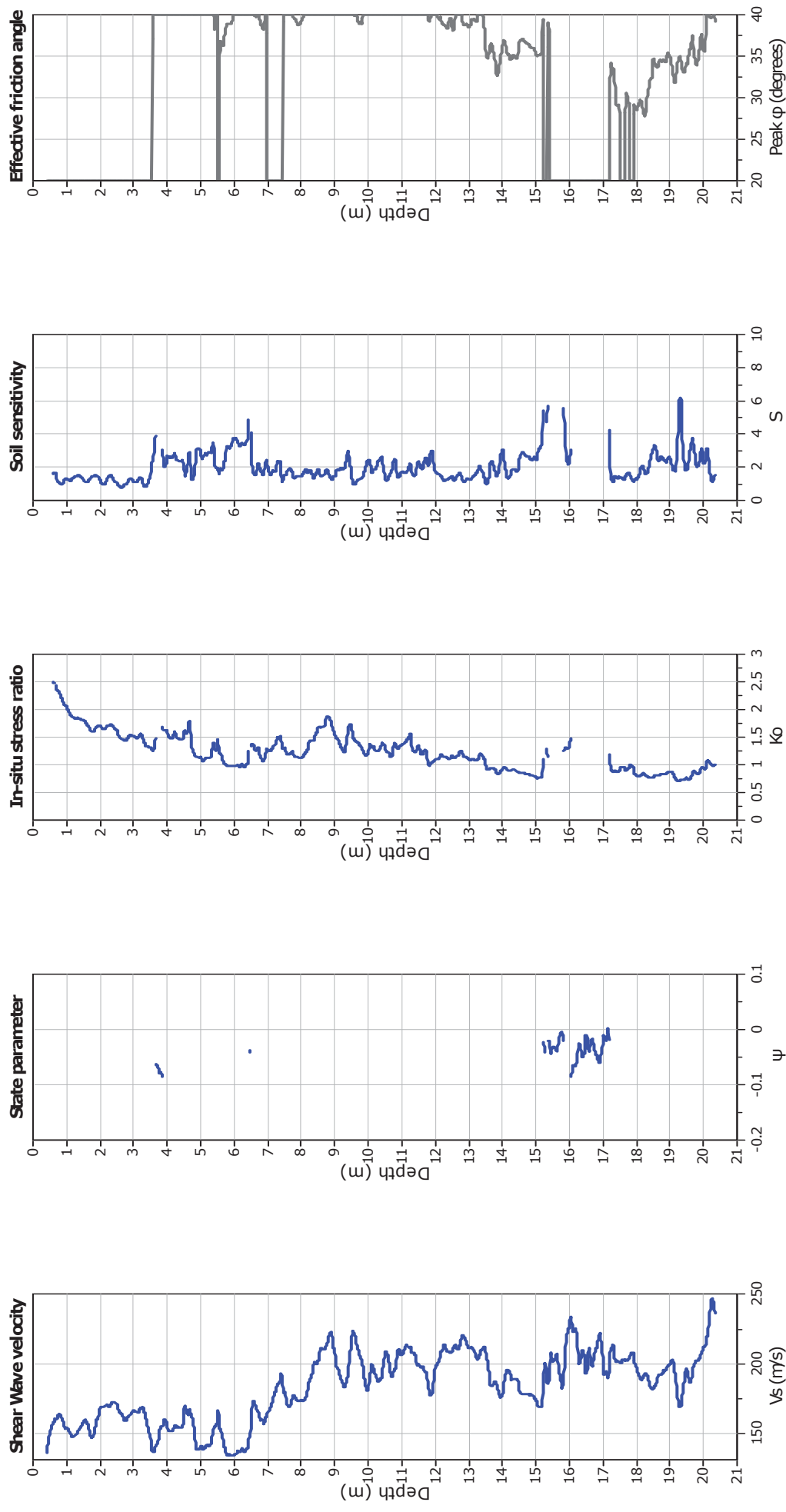
G_o : Based on variable $\alpha/\rho/\mu$ using I_c (Robertson, 2009)

Undrained shear strength cone factor for clays, N_{kt} : 14

OCR factor for clays, N_{kt} : 0.33

— User defined estimation data

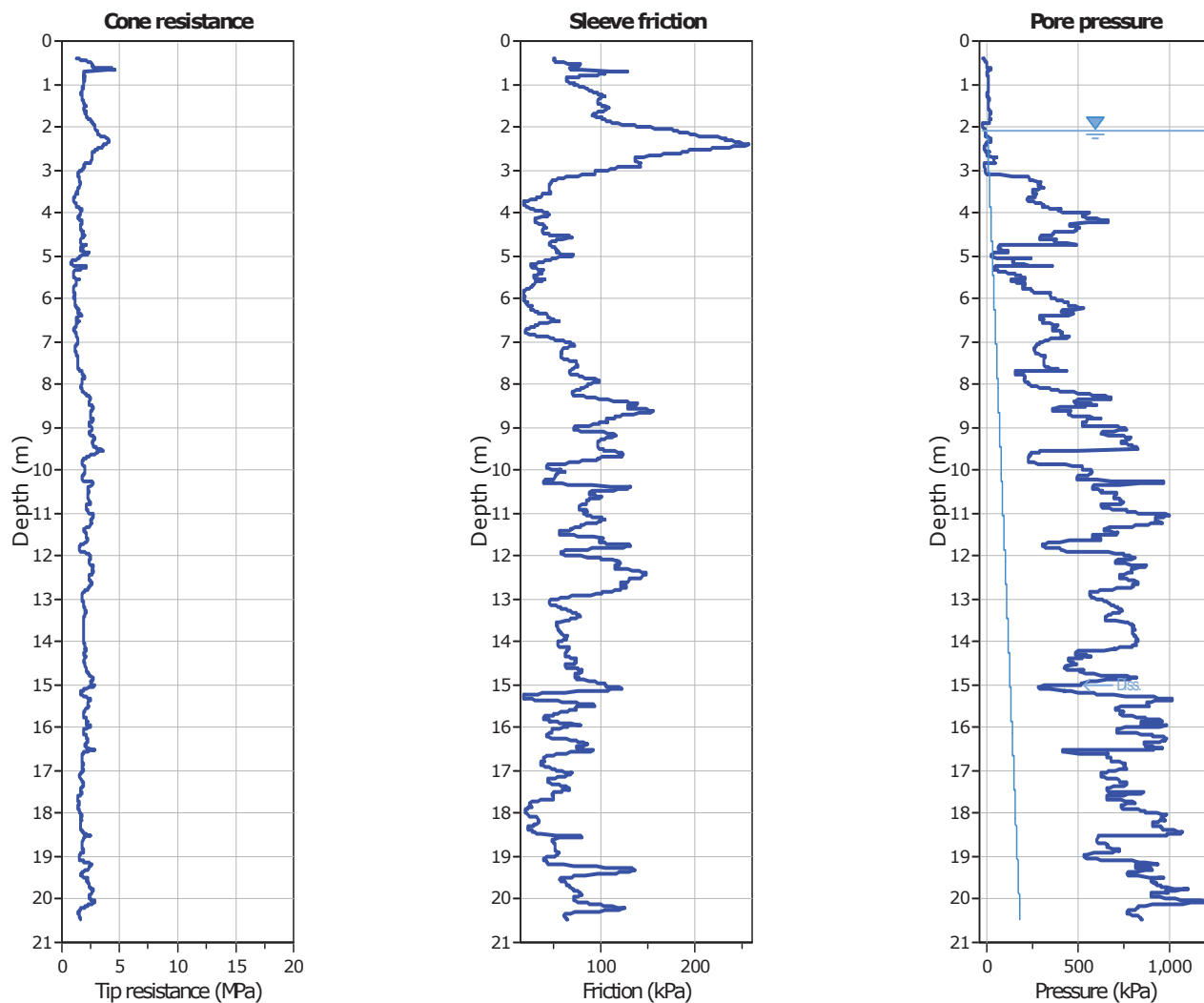
— Flat Dilatometer Test data



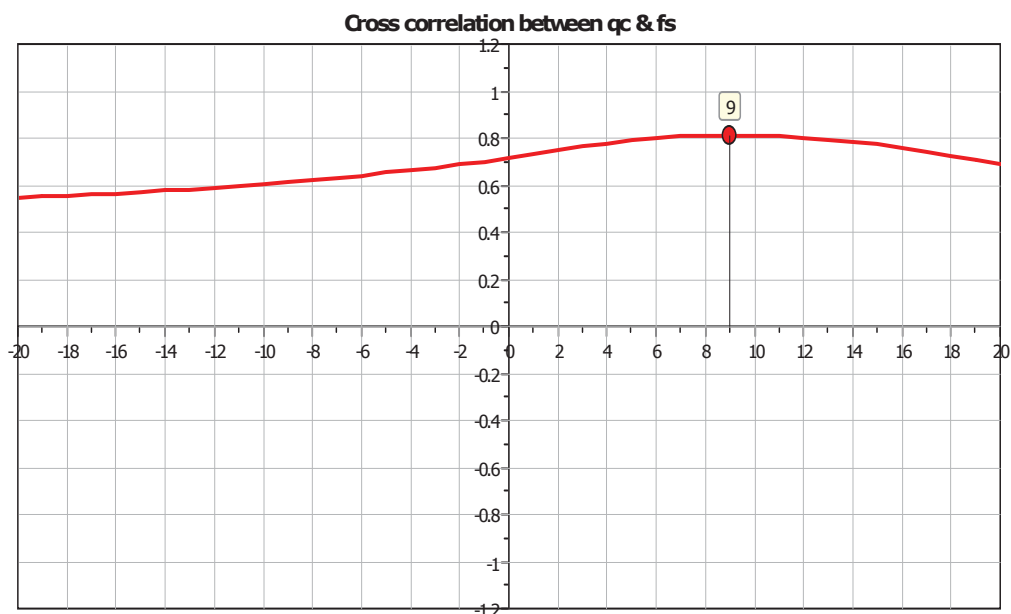
Calculation parameters

Soil Sensitivity factor, N_s : 7.00

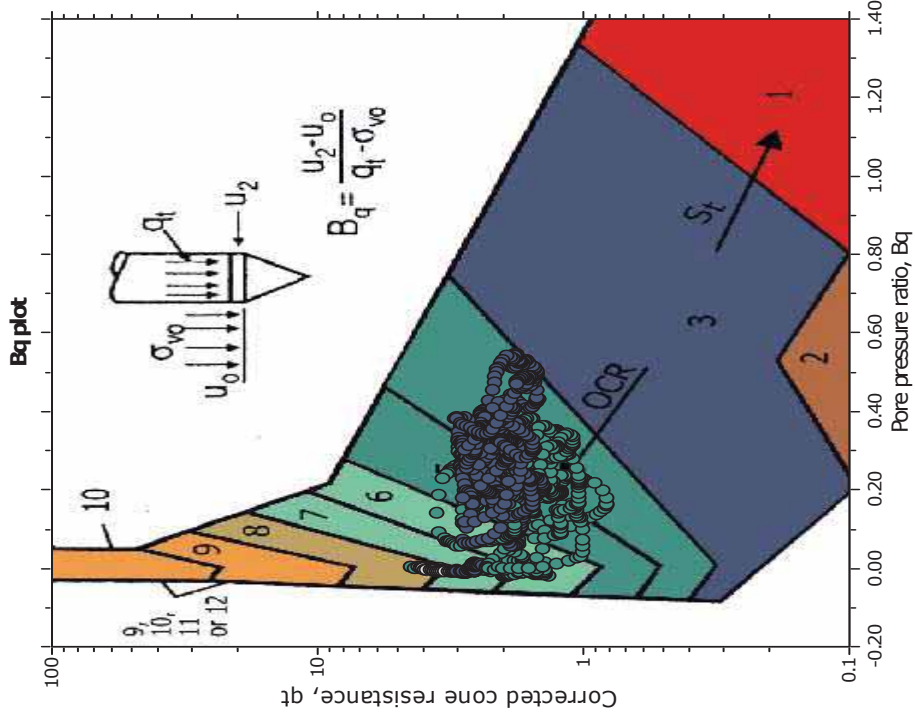
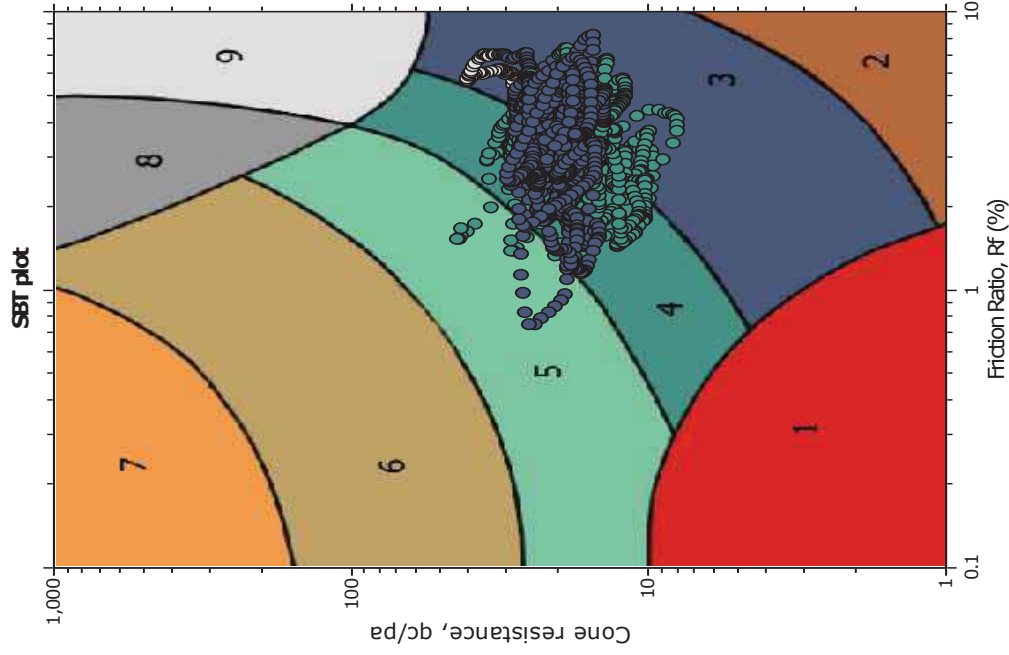
—●— User defined estimation data

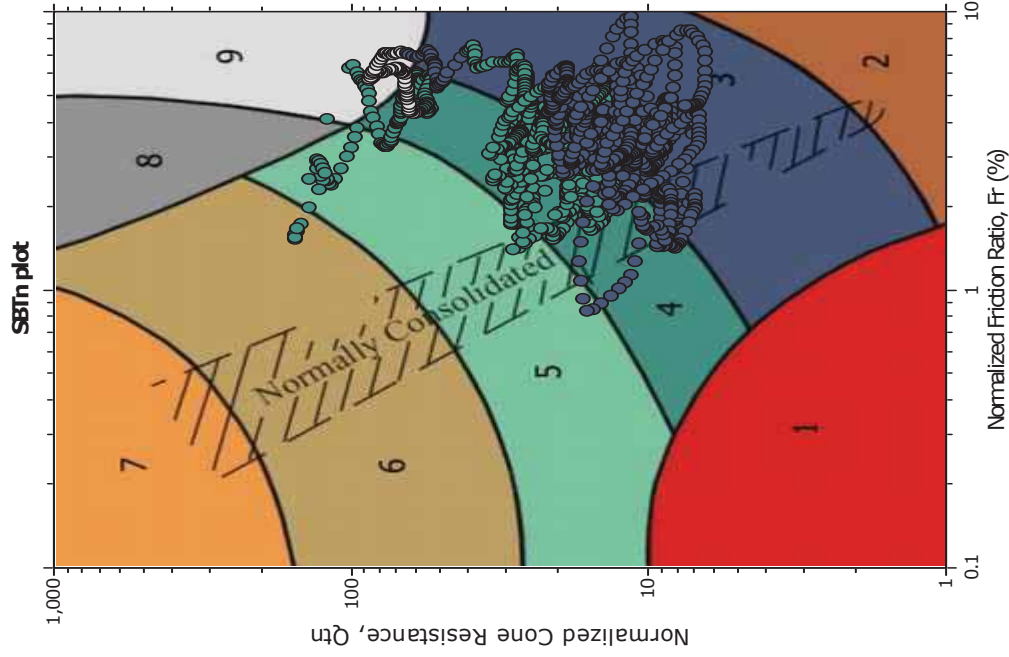


The plot below presents the cross correlation coefficient between the raw q_c and f_s values (as measured on the field). X axes presents the lag distance (one lag is the distance between two successive CPT measurements).

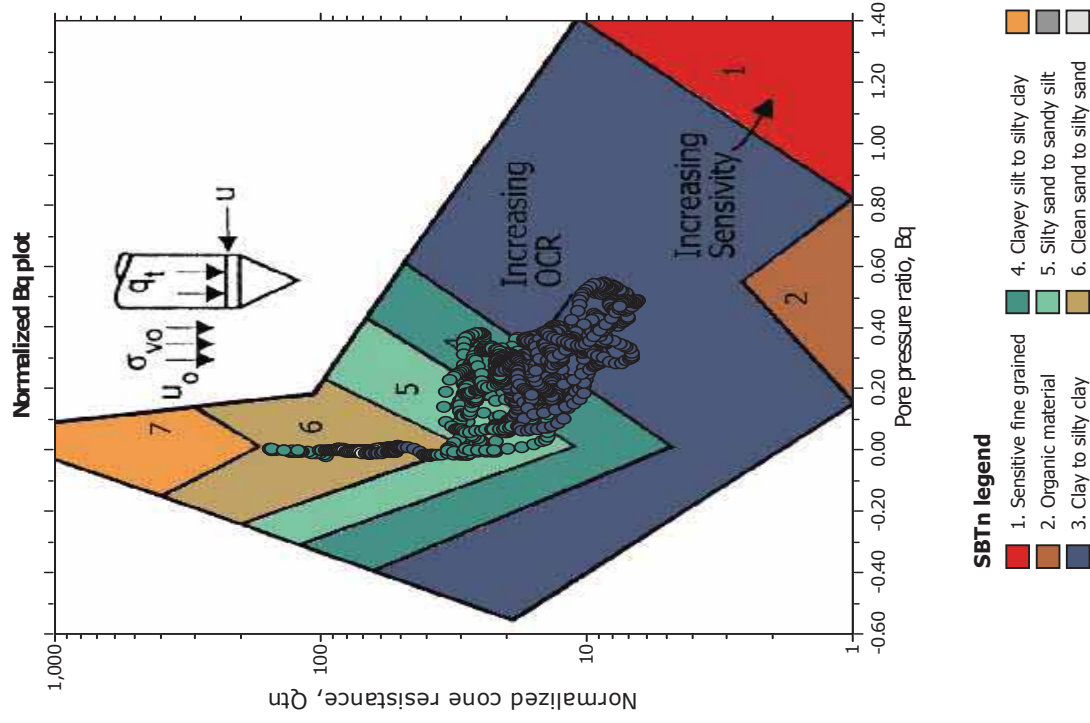


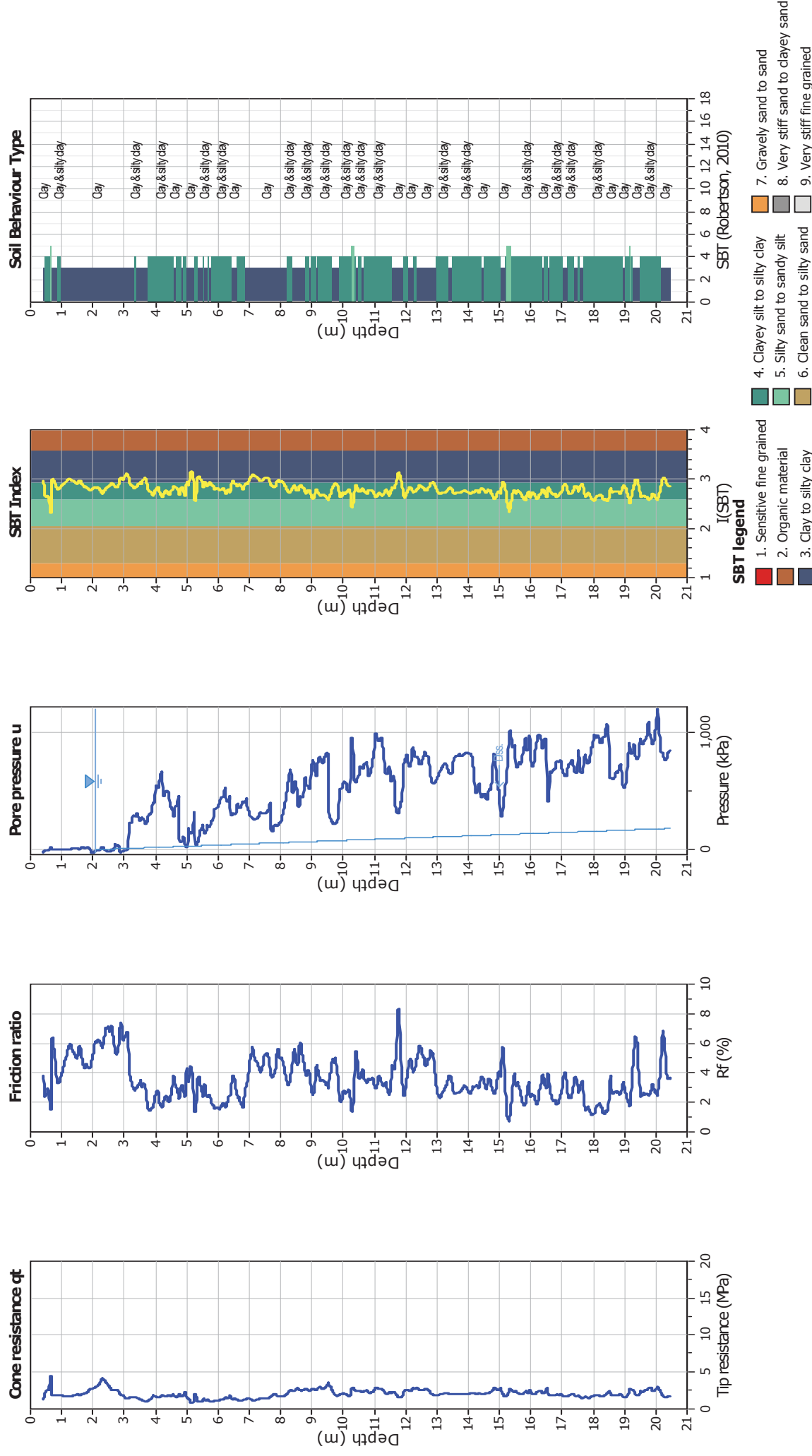
SBT - Bq plots

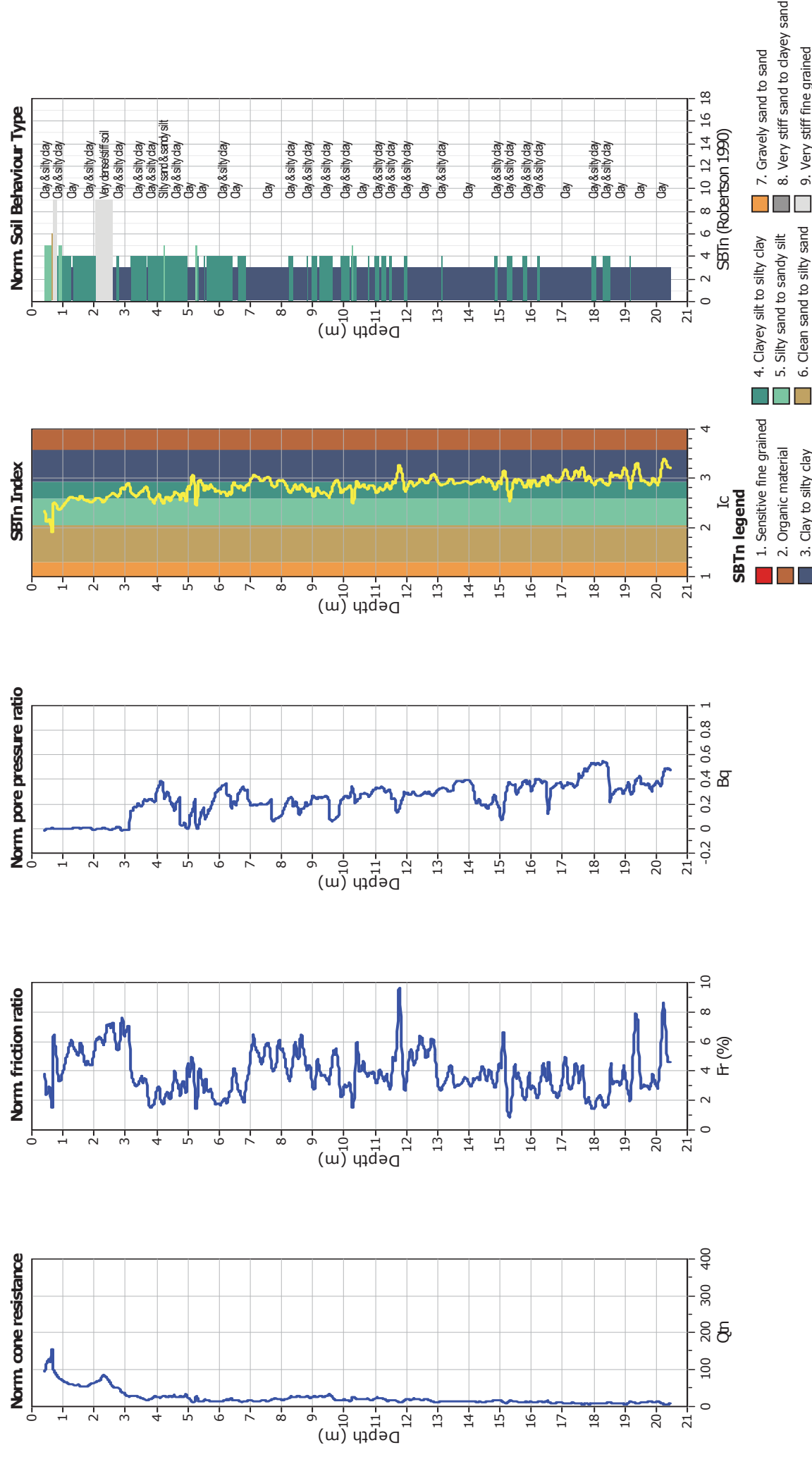


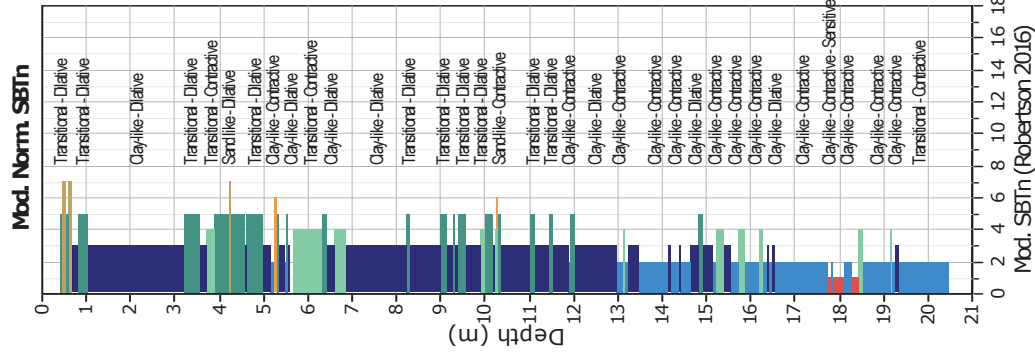
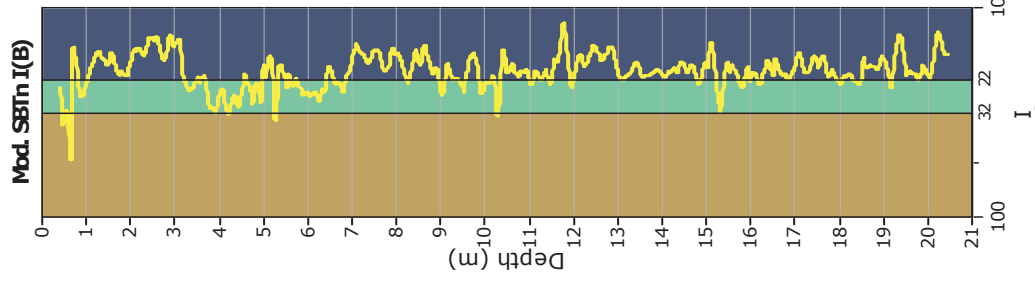
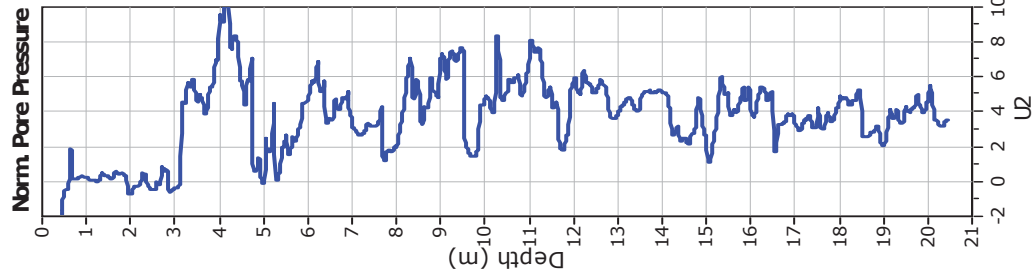
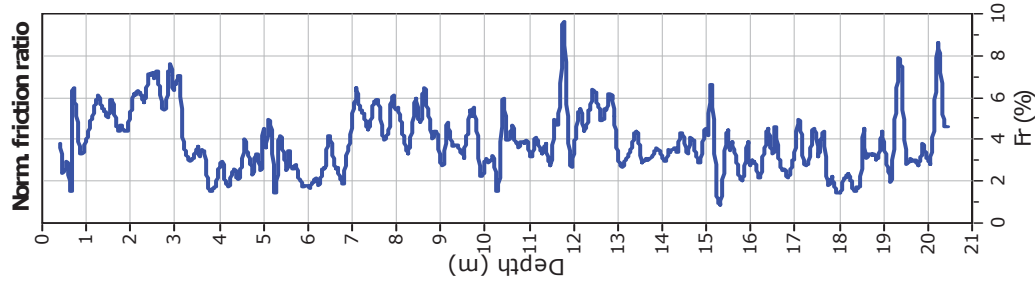
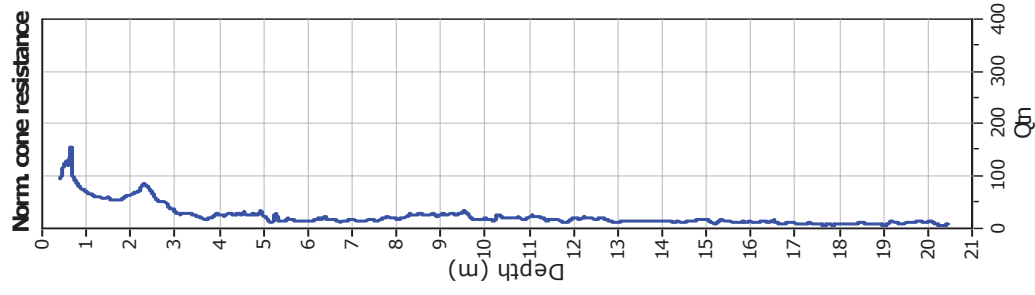


SBT - Bq plots (normalized)





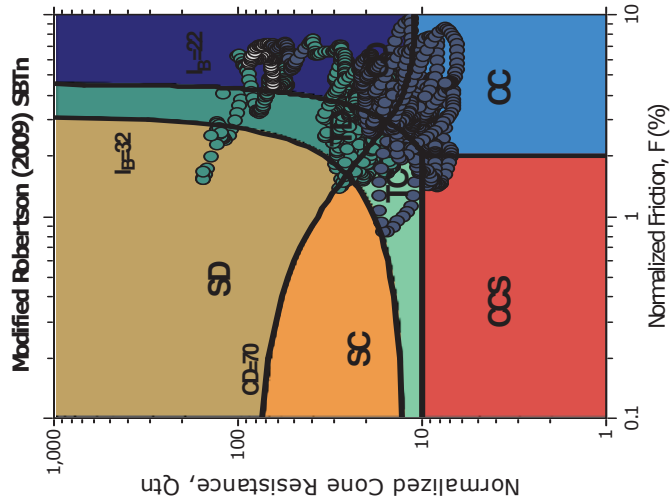




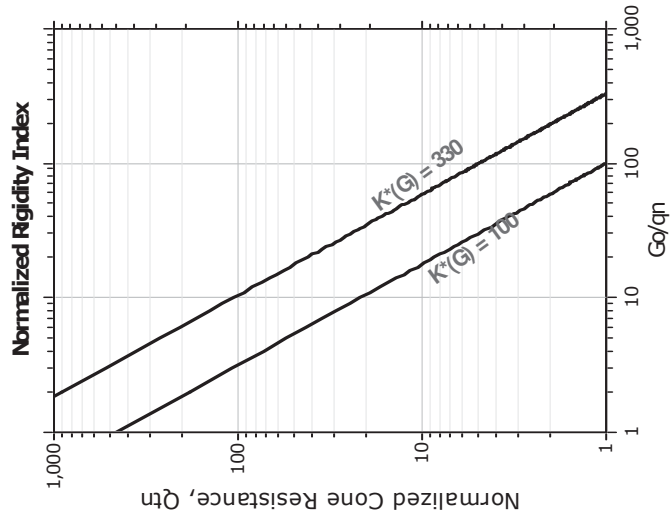
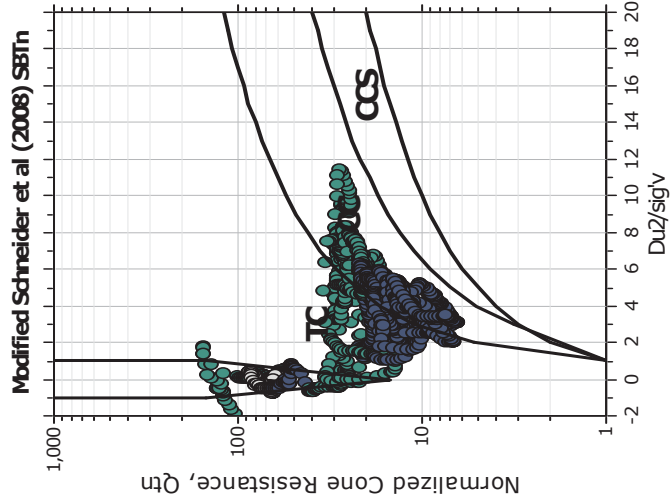
Mod. SBTn legend

- 1. CCS: ClayLike - Contractive, Sensitive
- 2. CC: Clay-like - Contractive
- 3. CD: Clay-Like: Dilative
- 4. TC: Transitional - Contractive
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- 7. SD: Sand-like - Dilative

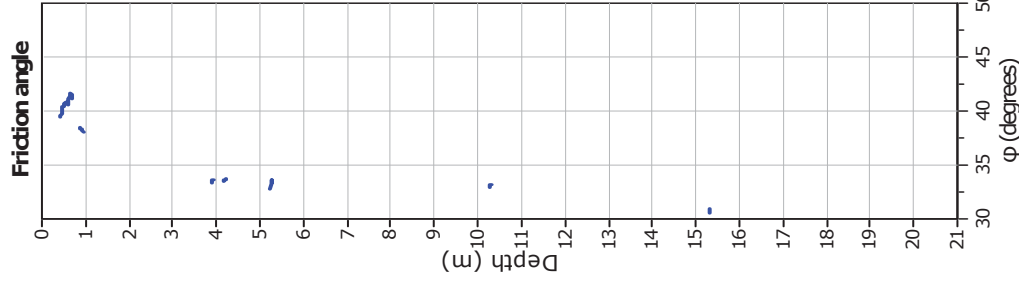
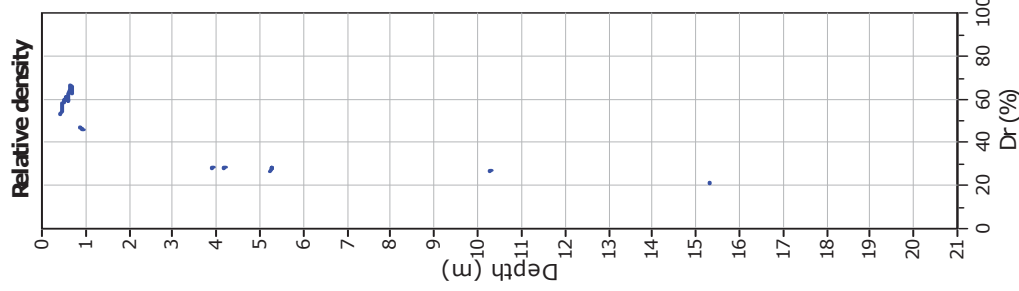
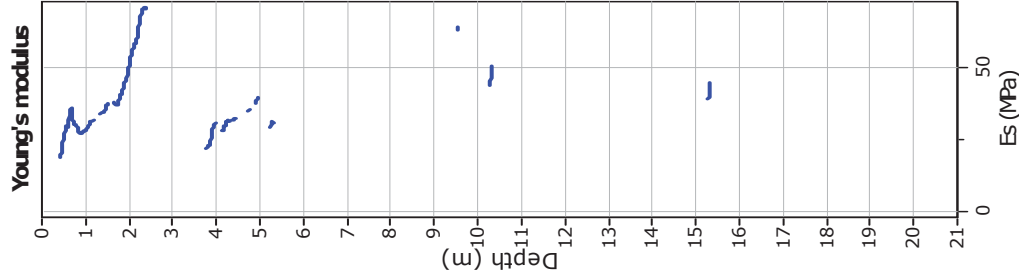
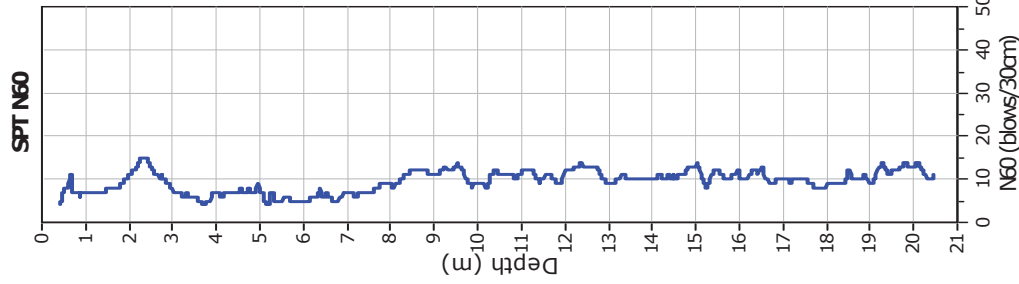
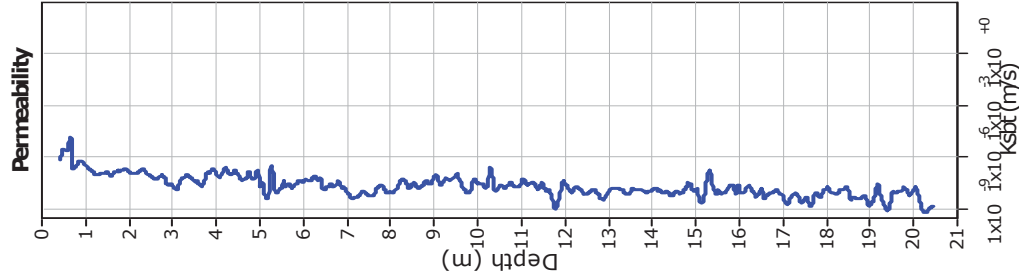
Updated SBTn plots



CCs: Clay-like - Contractive - Sensitive
CC: Clay-like - Contractive
CD: Clay-like - Dilative
TC: Transitional - Contractive
TD: Transitional - Dilative
SC: Sand-like - Contractive
SD: Sand-like - Dilative



$K(G) > 330$: Soils with significant microstructure
(e.g. age/cementation)



Calculation parameters

Permeability: Based on SBT_n

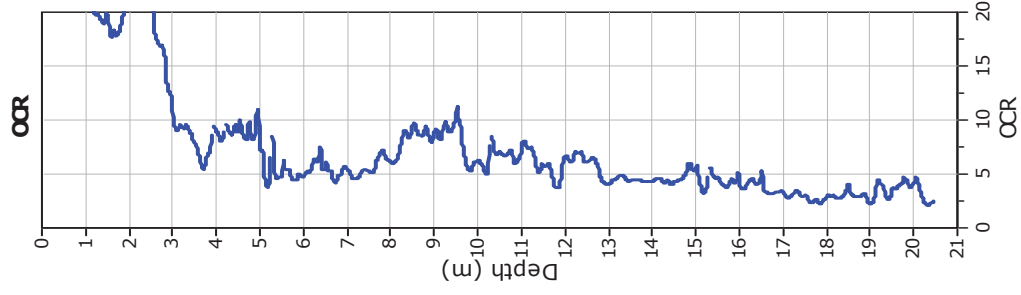
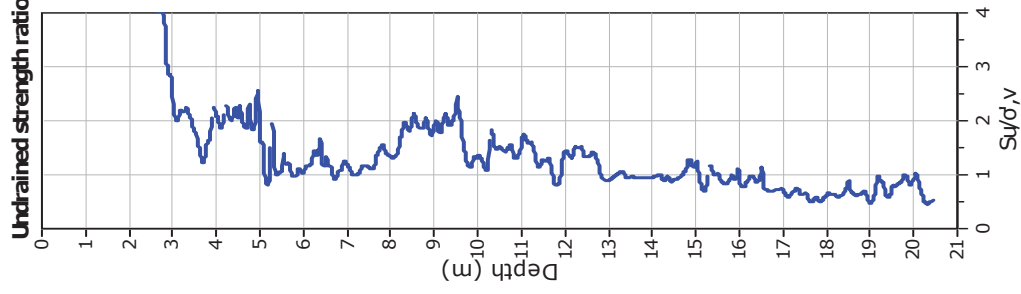
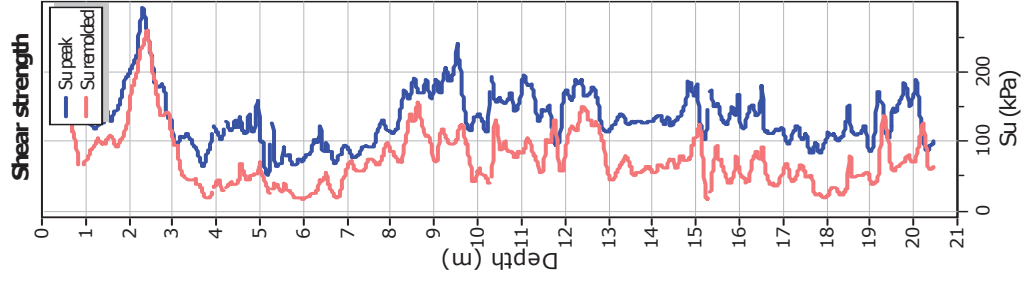
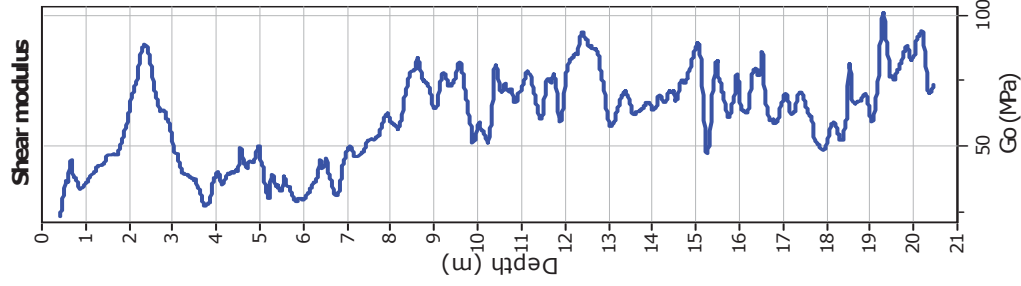
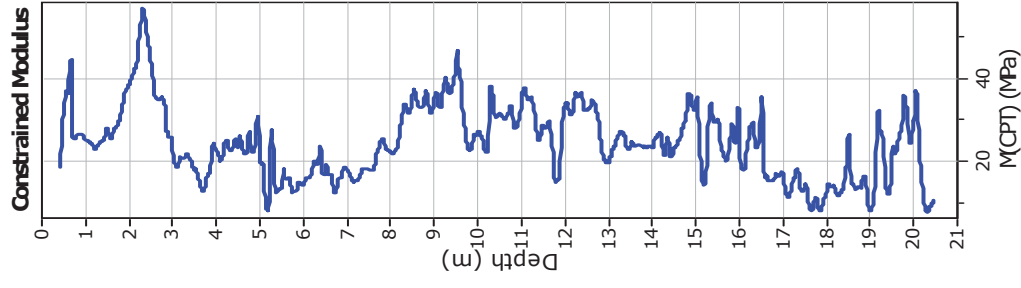
SPT N_{60} : Based on I_c and q_t

Young's modulus: Based on variable alpha using I_c (Robertson, 2009)

Relative density constant, C_{or} : 350.0

Phi: Based on Kulhawy & Mayne (1990)

—●— User defined estimation data



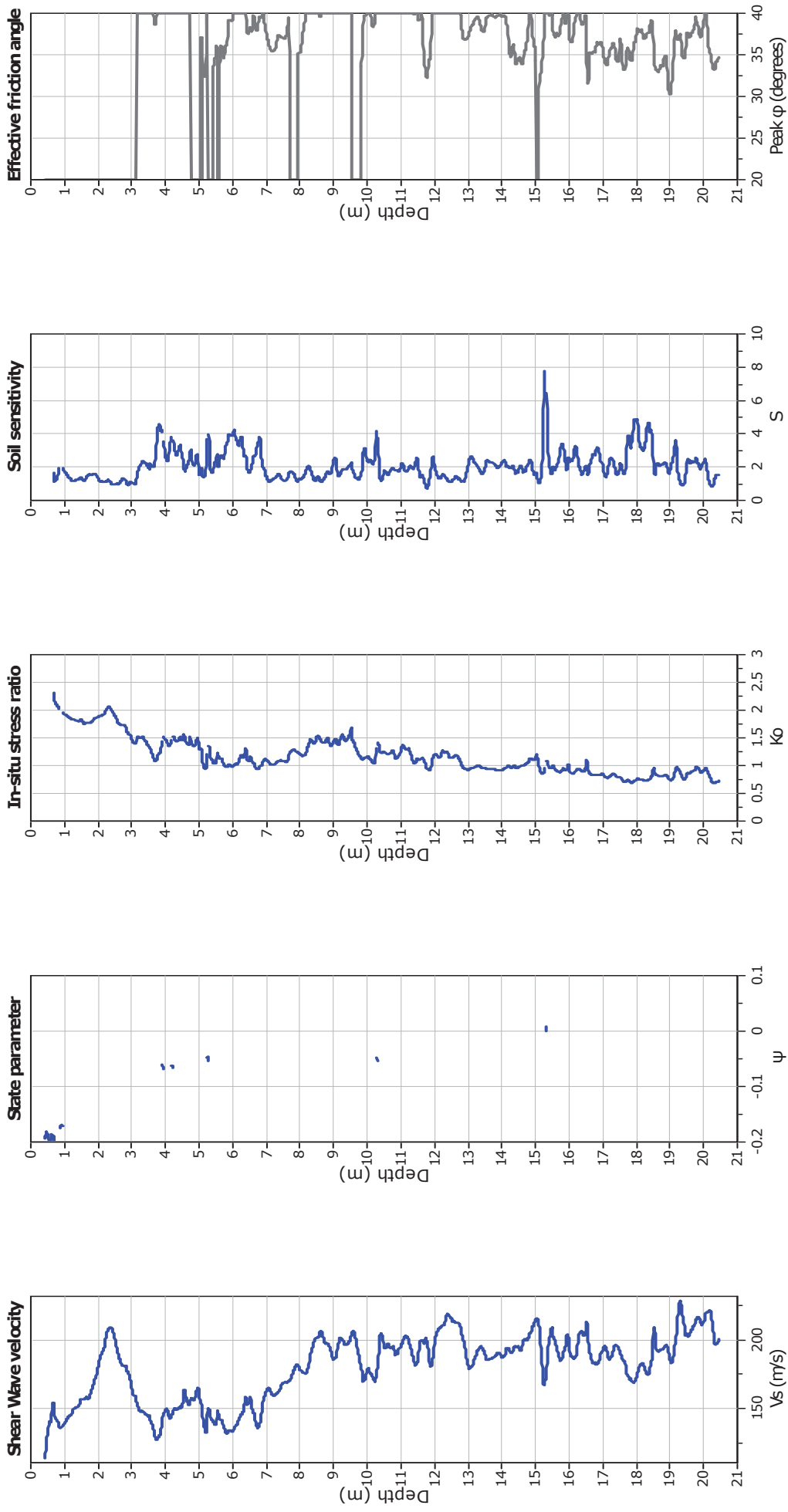
Calculation parameters

Constrained modulus: Based on variable $\alpha/\rho/\eta$ using I_c and Q_m (Robertson, 2009)
Go: Based on variable $\alpha/\rho/\eta$ using I_c (Robertson, 2009)

OCR factor for clays, N_{kt} : 0.33

—●— User defined estimation data
—●— Flat Dilatometer Test data

Undrained shear strength cone factor for clays, N_{kt} : 14



Calculation parameters

Soil Sensitivity factor, N_s : 7.00
—●— User defined estimation data

GEO GROUP s.r.l.

Indagini geognostiche e geofisiche – geologia applicata alle costruzioni – laboratorio geotecnico - idrogeologia
– coltivazione cave– bonifiche – consolidamenti – geologia ambientale – consulenze geologiche e geotecniche

ALLEGATO N° 2

Prove di dissipazione

Dissipation Tests Results

Dissipation tests

Dissipation tests consists of stopping the piezocone penetration and observing porepressures (u) with elapsed time (t). The data are automatic recorded by the field computer and should take place until a minimum of 50% dissipation.

The porepressures are plotted as a function of square root of (t). The graphical technique suggested by Robertson and Campanella (1989), yields a value for t_{50} , which corresponds to the time for 50% consolidation.

The value of the coefficient of consolidation in the radial or horizontal direction c_h was then calculated by Houlsby and Teh's (1988) theory using the following equation:

$$c_h = \frac{T \times r^2 \times I_r^{0.5}}{t_{50}}$$

where:

T: time factor given by Houlsby and Teh's (1988) theory corresponding to the porepressure position

r: piezocone radius

I_r : stiffness index, equal to shear modulus G divided by the undrained strength of clay (S_u).

t_{50} : time corresponding to 50% consolidation

Permeability estimates based on dissipation test

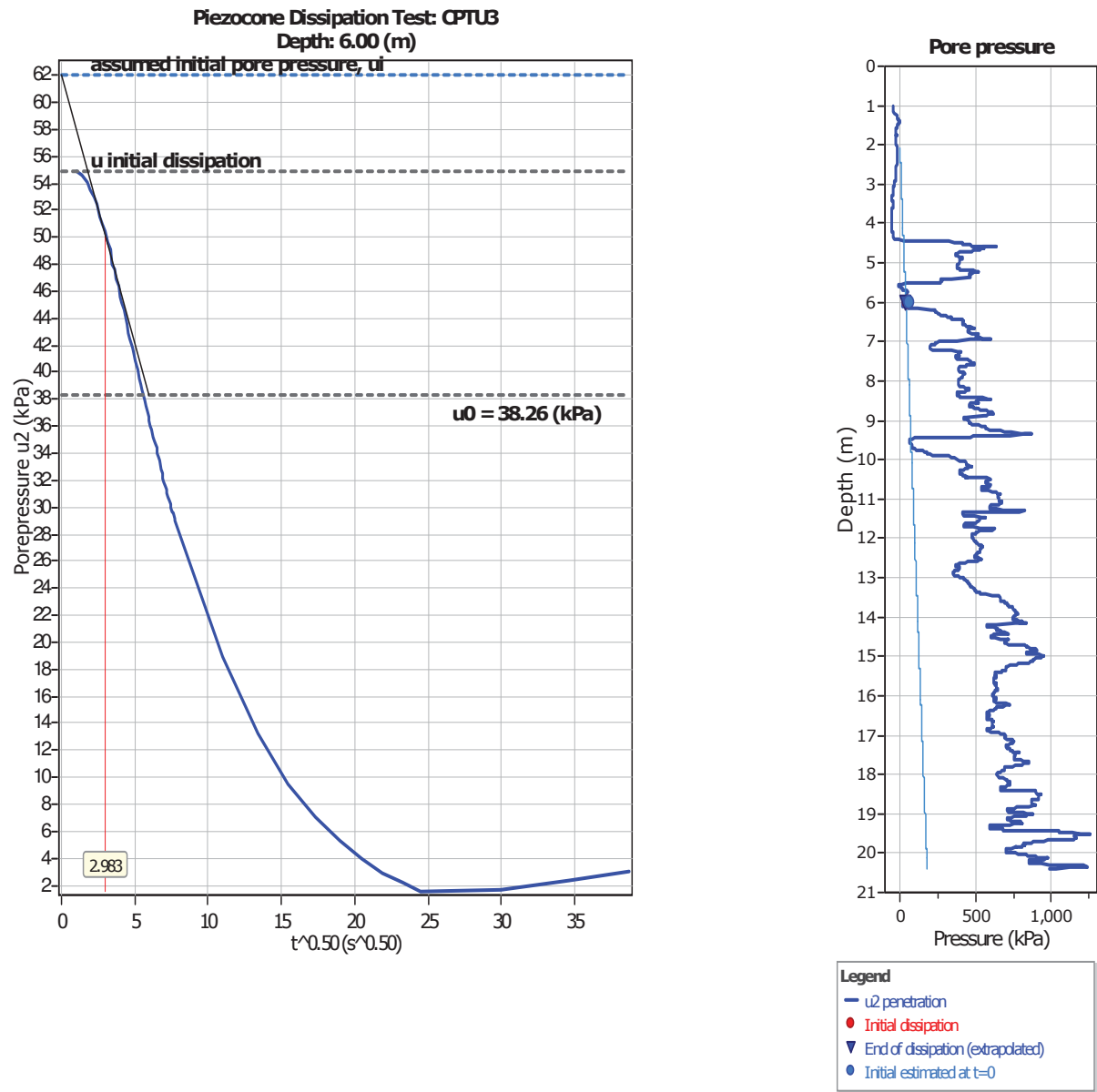
The dissipation of pore pressures during a CPTu dissipation test is controlled by the coefficient of consolidation in the horizontal direction (c_h) which is influenced by a combination of the soil permeability (k_h) and compressibility (M), as defined by the following:

$$k_h = c_h \times \gamma_w / M$$

where: M is the 1-D constrained modulus and γ_w is the unit weight of water, in compatible units.

Tabular results

| CPTU Borehole | Depth (m) | $(t_{50})^{0.50}$ | t_{50} (s) | t_{50} (years) | G/ S_u | c_h (m^2/s) | c_h ($m^2/year$) | M (MPa) | k_h (m/s) |
|---------------|-----------|-------------------|--------------|------------------|----------|-------------------|----------------------|---------|-------------|
| CPTU3 | 6.00 | 3.0 | 9 | 2.82E-007 | 444.29 | 1.94E-004 | 6129 | 22.81 | 8.36E-008 |



Dissipation Tests Results

Dissipation tests

Dissipation tests consists of stopping the piezocone penetration and observing porepressures (u) with elapsed time (t). The data are automatic recorded by the field computer and should take place until a minimum of 50% dissipation.

The porepressures are plotted as a function of square root of (t). The graphical technique suggested by Robertson and Campanella (1989), yields a value for t_{50} , which corresponds to the time for 50% consolidation.

The value of the coefficient of consolidation in the radial or horizontal direction c_h was then calculated by Houlsby and Teh's (1988) theory using the following equation:

$$c_h = \frac{T \times r^2 \times I_r^{0.5}}{t_{50}}$$

where:

T: time factor given by Houlsby and Teh's (1988) theory corresponding to the porepressure position

r: piezocone radius

I_r : stiffness index, equal to shear modulus G divided by the undrained strength of clay (S_u).

t_{50} : time corresponding to 50% consolidation

Permeability estimates based on dissipation test

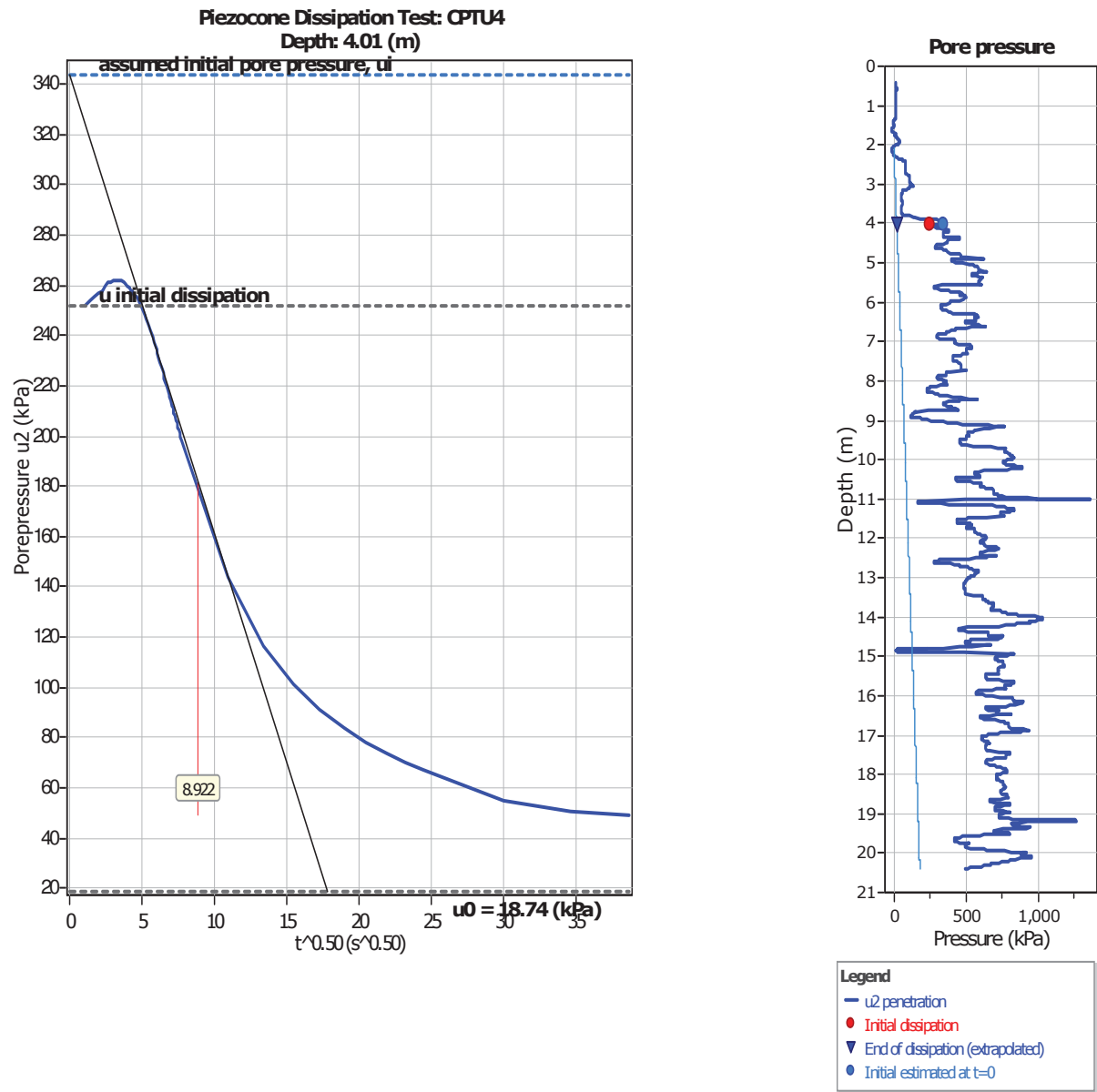
The dissipation of pore pressures during a CPTu dissipation test is controlled by the coefficient of consolidation in the horizontal direction (c_h) which is influenced by a combination of the soil permeability (k_h) and compressibility (M), as defined by the following:

$$k_h = c_h \times \gamma_w / M$$

where: M is the 1-D constrained modulus and γ_w is the unit weight of water, in compatible units.

Tabular results

| CPTU Borehole | Depth (m) | $(t_{50})^{0.50}$ | t_{50} (s) | t_{50} (years) | G/ S_u | c_h (m^2/s) | c_h ($m^2/year$) | M (MPa) | k_h (m/s) |
|---------------|-----------|-------------------|--------------|------------------|----------|-------------------|----------------------|---------|-------------|
| CPTU4 | 4.01 | 8.9 | 80 | 2.52E-006 | 321.53 | 1.85E-005 | 583 | 25.66 | 7.06E-009 |



Dissipation Tests Results

Dissipation tests

Dissipation tests consists of stopping the piezocone penetration and observing porepressures (u) with elapsed time (t). The data are automatic recorded by the field computer and should take place until a minimum of 50% dissipation.

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T: time factor given by Houlsby and Teh's (1988) theory corresponding to the porepressure position

r: piezocone radius

I_r : stiffness index, equal to shear modulus G divided by the undrained strength of clay (S_u).

t_{50} : time corresponding to 50% consolidation

Permeability estimates based on dissipation test

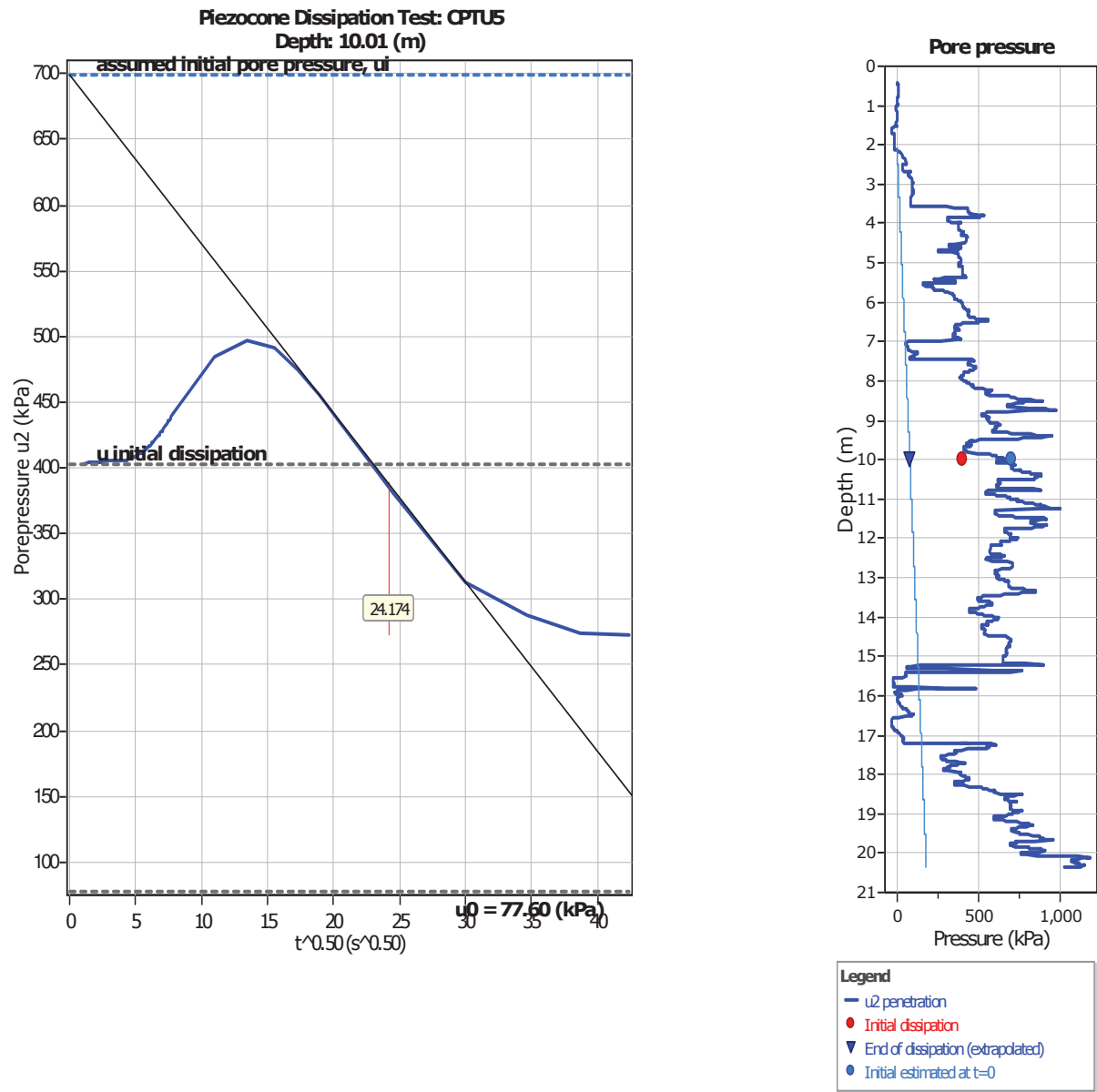
The dissipation of pore pressures during a CPTu dissipation test is controlled by the coefficient of consolidation in the horizontal direction (c_h) which is influenced by a combination of the soil permeability (k_h) and compressibility (M), as defined by the following:

$$k_h = c_h \times \gamma_w / M$$

where: M is the 1-D constrained modulus and γ_w is the unit weight of water, in compatible units.

Tabular results

| CPTU Borehole | Depth (m) | $(t_{50})^{0.50}$ | t_{50} (s) | t_{50} (years) | G/ S_u | c_h (m^2/s) | c_h ($m^2/year$) | M (MPa) | k_h (m/s) |
|---------------|-----------|-------------------|--------------|------------------|----------|-------------------|----------------------|---------|-------------|
| CPTU5 | 10.01 | 24.2 | 584 | 1.85E-005 | 395.64 | 2.79E-006 | 88 | 30.95 | 8.85E-010 |



Dissipation Tests Results

Dissipation tests

Dissipation tests consists of stopping the piezocone penetration and observing porepressures (u) with elapsed time (t). The data are automatic recorded by the field computer and should take place until a minimum of 50% dissipation.

The porepressures are plotted as a function of square root of (t). The graphical technique suggested by Robertson and Campanella (1989), yields a value for t_{50} , which corresponds to the time for 50% consolidation.

The value of the coefficient of consolidation in the radial or horizontal direction c_h was then calculated by Houlsby and Teh's (1988) theory using the following equation:

$$c_h = \frac{T \times r^2 \times I_r^{0.5}}{t_{50}}$$

where:

T: time factor given by Houlsby and Teh's (1988) theory corresponding to the porepressure position

r: piezocone radius

I_r : stiffness index, equal to shear modulus G divided by the undrained strength of clay (S_u).

t_{50} : time corresponding to 50% consolidation

Permeability estimates based on dissipation test

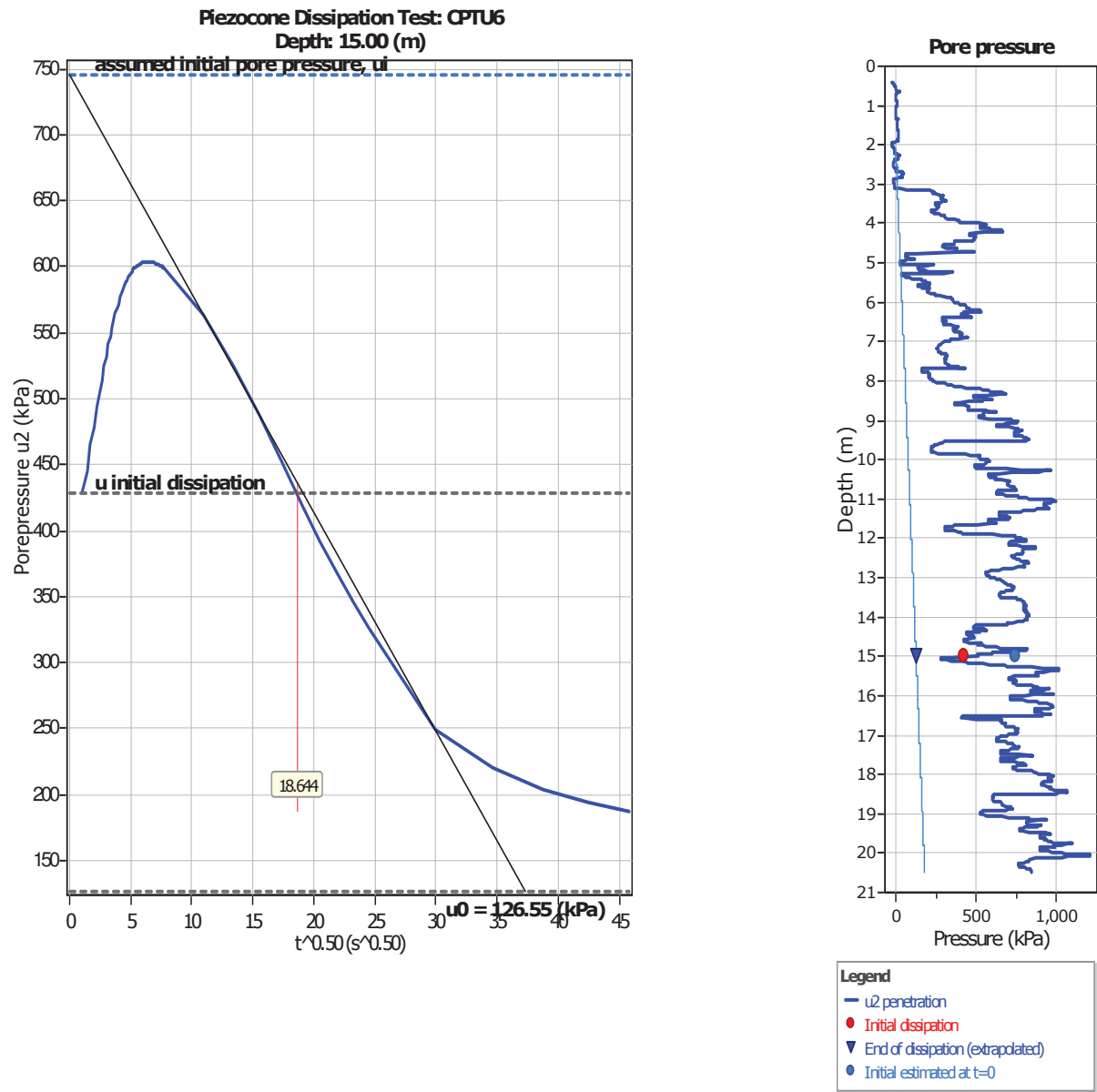
The dissipation of pore pressures during a CPTu dissipation test is controlled by the coefficient of consolidation in the horizontal direction (c_h) which is influenced by a combination of the soil permeability (k_h) and compressibility (M), as defined by the following:

$$k_h = c_h \times \gamma_w / M$$

where: M is the 1-D constrained modulus and γ_w is the unit weight of water, in compatible units.

Tabular results

| CPTU Borehole | Depth (m) | $(t_{50})^{0.50}$ | t_{50} (s) | t_{50} (years) | G/ S_u | c_h (m^2/s) | c_h ($m^2/year$) | M (MPa) | k_h (m/s) |
|---------------|-----------|-------------------|--------------|------------------|----------|-------------------|----------------------|---------|-------------|
| CPTU6 | 15.00 | 18.6 | 348 | 1.10E-005 | 513.13 | 5.35E-006 | 169 | 33.31 | 1.57E-009 |



GEO GROUP s.r.l.

Indagini geognostiche e geofisiche – geologia applicata alle costruzioni – laboratorio geotecnico - idrogeologia
– coltivazione cave– bonifiche – consolidamenti – geologia ambientale – consulenze geologiche e geotecniche

ALLEGATO N° 3

Indagini sismiche

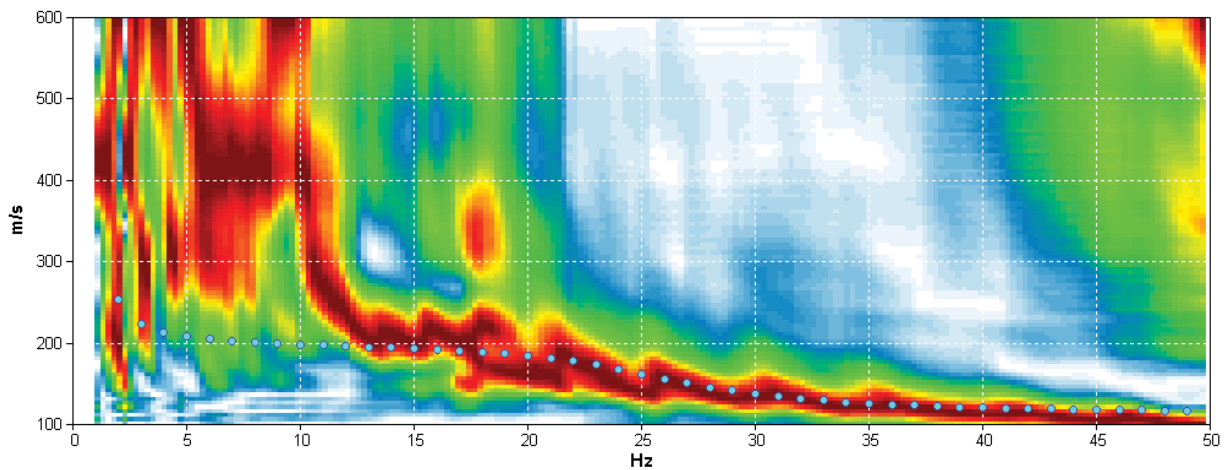
FOSSOLI, MASW

Start recording: 04/09/19 09:15:30 End recording: 04/09/19 09:15:32
Trace length: 0h00'02". Analyzed 100% trace (manual window selection)
Sampling rate: 4000 Hz

Channel labels: CH01 ; CH02 ; CH03 ; CH04 ; CH05 ; CH06 ; CH07 ;
CH08 ; CH09 ; CH10 ; CH11 ; CH12 ; CH13 ; CH14 ; CH15 ; CH16
; CH17 ; CH18 ; CH19 ; CH20 ; CH21 ; CH22 ; CH23

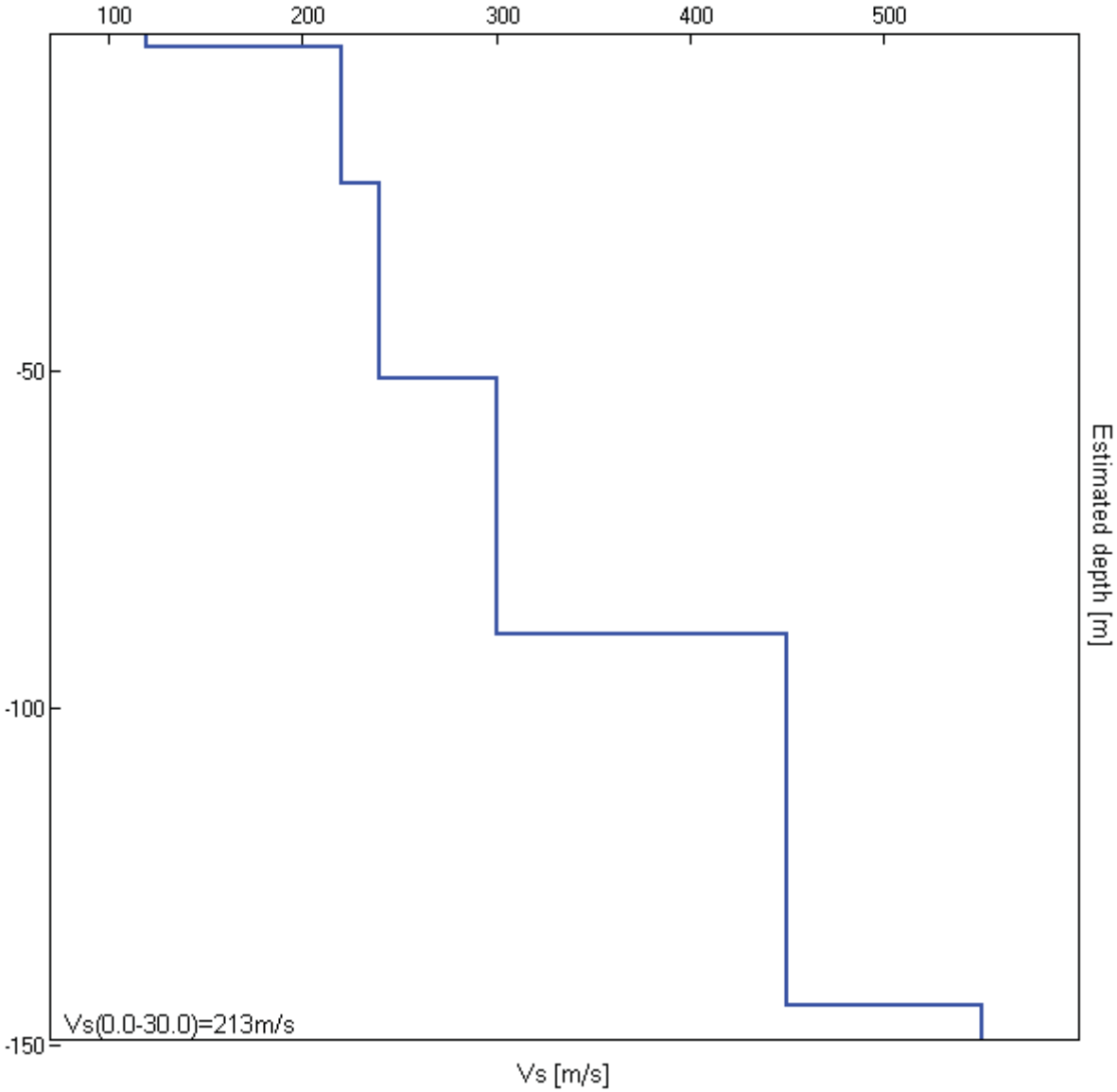
Array geometry (x): 0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0 16.0 18.0 20.0 22.0 24.0 26.0 28.0 30.0 32.0 34.0 36.0
38.0 40.0 42.0 44.0 m.

MODELLED RAYLEIGH WAVE PHASE VELOCITY DISPERSION CURVE



| Depth at the bottom of the layer [m] | Thickness [m] | Vs [m/s] | Poisson ratio |
|--------------------------------------|---------------|----------|---------------|
| 2.00 | 2.00 | 120 | 0.45 |
| 22.00 | 20.00 | 220 | 0.45 |
| 51.00 | 29.00 | 240 | 0.45 |
| 89.00 | 38.00 | 300 | 0.45 |
| 144.00 | 55.00 | 450 | 0.45 |
| inf. | inf. | 550 | 0.45 |

Vs(0.0-30.0)=213m/s



FOSSOLI AIMAG

Instrument: TE3-0303/01-17

Data format: 16 byte

Full scale [mV]: 51

Start recording: 04/09/19 09:18:15 End recording: 04/09/19 09:38:15

Channel labels: NORTH SOUTH; EAST WEST; UP DOWN

GPS data not available

Trace length: 0h20'00". Analyzed 100% trace (manual window selection)

Sampling rate: 128 Hz

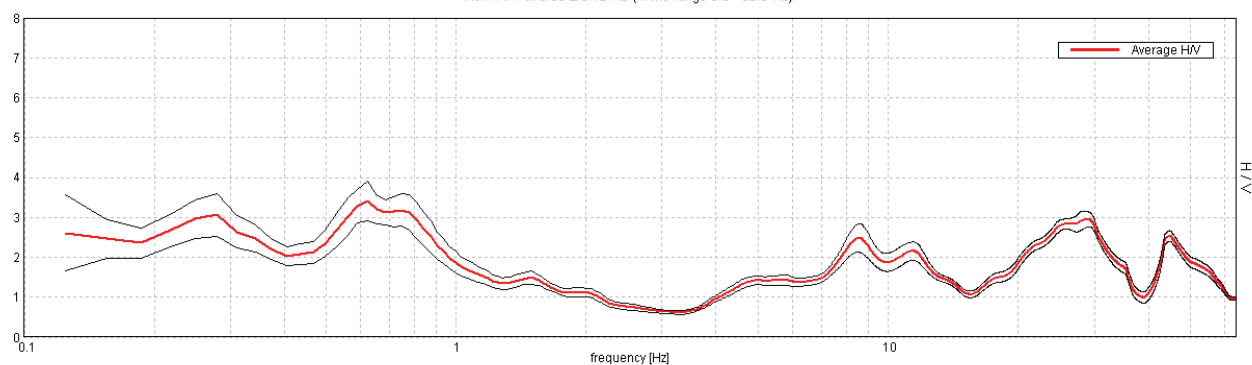
Window size: 20 s

Smoothing type: Triangular window

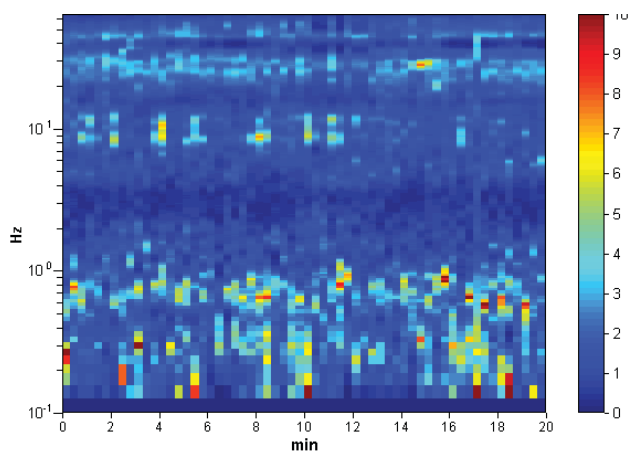
Smoothing: 10%

HORIZONTAL TO VERTICAL SPECTRAL RATIO

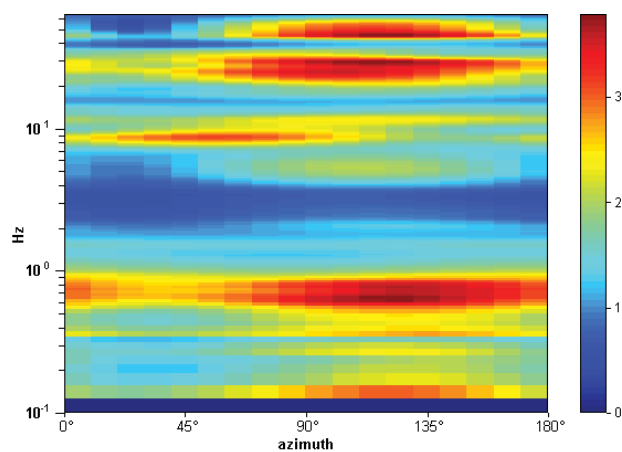
Max. H/V at 0.63 ± 0.12 Hz (in the range 0.0 - 30.0 Hz).



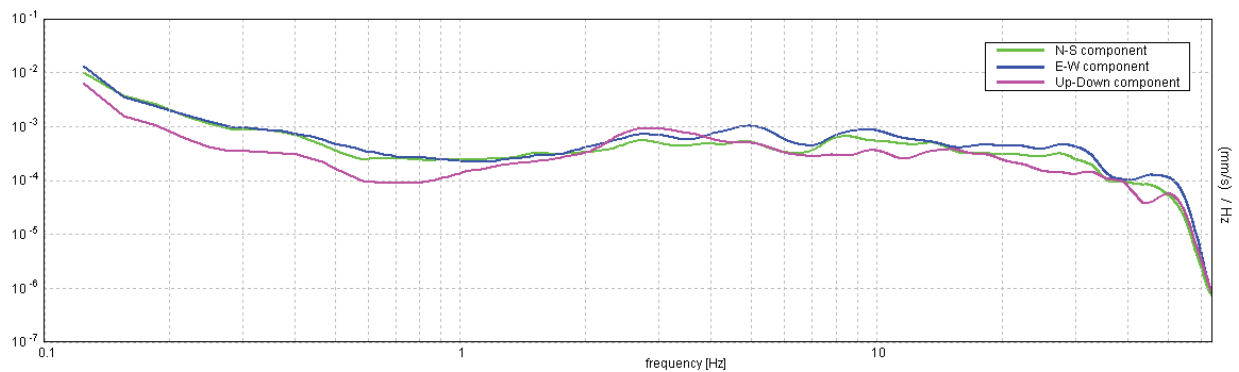
H/V TIME HISTORY



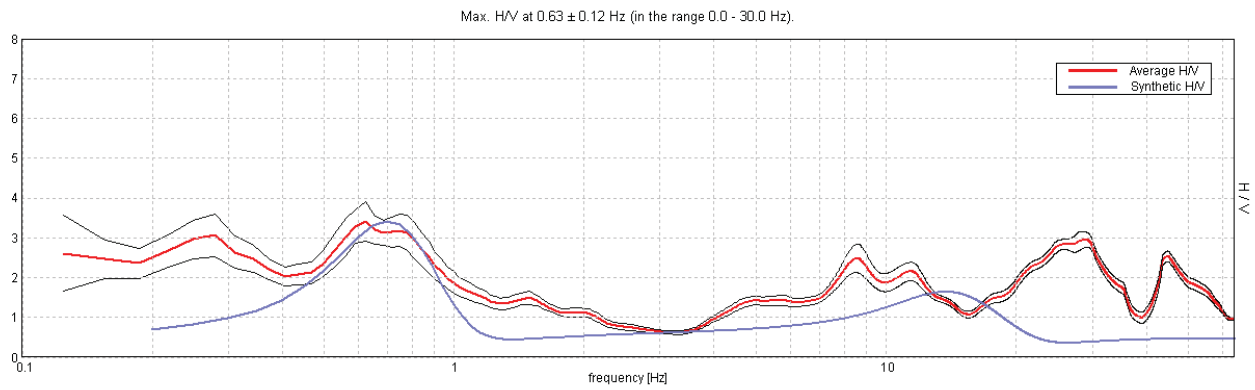
DIRECTIONAL H/V



SINGLE COMPONENT SPECTRA

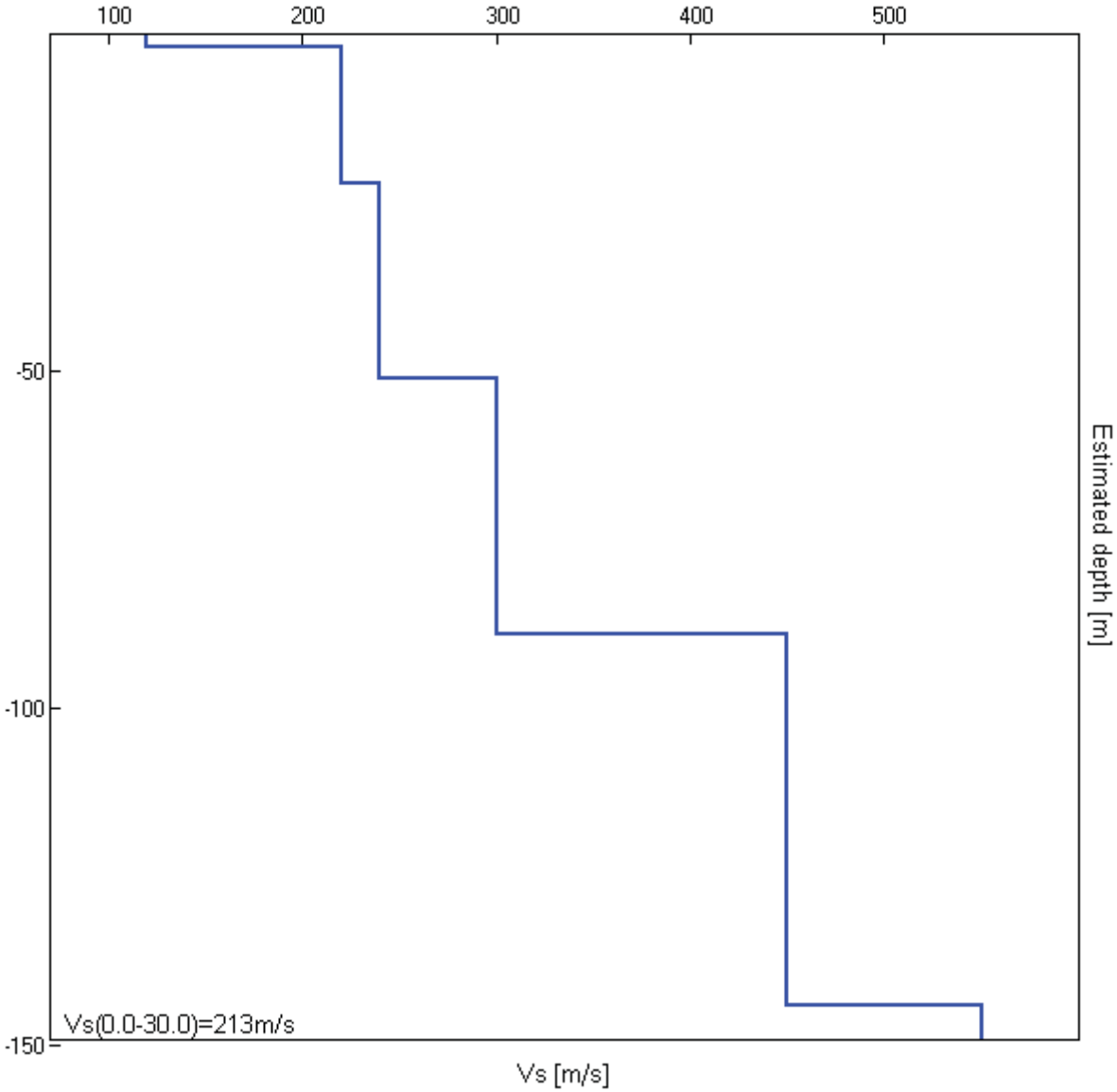


EXPERIMENTAL vs. SYNTHETIC H/V



| Depth at the bottom of the layer [m] | Thickness [m] | Vs [m/s] | Poisson ratio |
|--------------------------------------|---------------|----------|---------------|
| 2.00 | 2.00 | 120 | 0.42 |
| 22.00 | 20.00 | 220 | 0.42 |
| 51.00 | 29.00 | 240 | 0.42 |
| 89.00 | 38.00 | 300 | 0.42 |
| 144.00 | 55.00 | 450 | 0.42 |
| inf. | inf. | 550 | 0.42 |

Vs(0.0-30.0)=213m/s



[According to the SESAME, 2005 guidelines. **Please read carefully the *Grilla* manual before interpreting the following tables.**]

Max. H/V at 0.63 ± 0.12 Hz (in the range 0.0 - 30.0 Hz).

Criteria for a reliable H/V curve

[All 3 should be fulfilled]

| | | | |
|--|----------------------------|----|--|
| $f_0 > 10 / L_w$ | $0.63 > 0.50$ | OK | |
| $n_c(f_0) > 200$ | $750.0 > 200$ | OK | |
| $\sigma_A(f) < 2$ for $0.5f_0 < f < 2f_0$ if $f_0 > 0.5\text{Hz}$ $\sigma_A(f) < 3$ for $0.5f_0 < f < 2f_0$ if $f_0 < 0.5\text{Hz}$ | Exceeded 0 out of 31 times | OK | |

Criteria for a clear H/V peak

[At least 5 out of 6 should be fulfilled]

| | | | |
|---|--------------------|----|----|
| Exists f^- in $[f_0/4, f_0]$ $A_{H/V}(f^-) < A_0 / 2$ | | | NO |
| Exists f^+ in $[f_0, 4f_0]$ $A_{H/V}(f^+) < A_0 / 2$ | 1.063 Hz | OK | |
| $A_0 > 2$ | $3.41 > 2$ | OK | |
| $f_{\text{peak}}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$ | $ 0.18753 < 0.05$ | | NO |
| $\sigma_f < \varepsilon(f_0)$ | $0.1172 < 0.09375$ | | NO |
| $\sigma_A(f_0) < \theta(f_0)$ | $0.5073 < 2.0$ | OK | |

| | |
|------------------------|---|
| L_w | window length |
| n_w | number of windows used in the analysis |
| $n_c = L_w n_w f_0$ | number of significant cycles |
| f | current frequency |
| f_0 | H/V peak frequency |
| σ_f | standard deviation of H/V peak frequency |
| $\varepsilon(f_0)$ | threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$ |
| A_0 | H/V peak amplitude at frequency f_0 |
| $A_{H/V}(f)$ | H/V curve amplitude at frequency f |
| f^- | frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$ |
| f^+ | frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$ |
| $\sigma_A(f)$ | standard deviation of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor by which the mean $A_{H/V}(f)$ curve should be multiplied or divided |
| $\sigma_{\log H/V}(f)$ | standard deviation of $\log A_{H/V}(f)$ curve |
| $\theta(f_0)$ | threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$ |

Threshold values for σ_f and $\sigma_A(f_0)$

| Freq. range [Hz] | < 0.2 | $0.2 - 0.5$ | $0.5 - 1.0$ | $1.0 - 2.0$ | > 2.0 |
|---|------------|-------------|-------------|-------------|------------|
| $\varepsilon(f_0)$ [Hz] | $0.25 f_0$ | $0.2 f_0$ | $0.15 f_0$ | $0.10 f_0$ | $0.05 f_0$ |
| $\theta(f_0)$ for $\sigma_A(f_0)$ | 3.0 | 2.5 | 2.0 | 1.78 | 1.58 |
| $\log \theta(f_0)$ for $\sigma_{\log H/V}(f_0)$ | 0.48 | 0.40 | 0.30 | 0.25 | 0.20 |

GEO GROUP s.r.l.

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ALLEGATO N° 4

Verifica alla liquefazione

LIQUEFACTION ANALYSIS REPORT

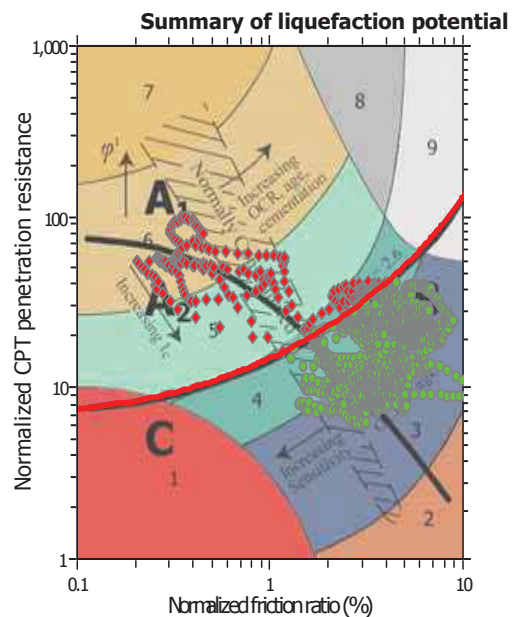
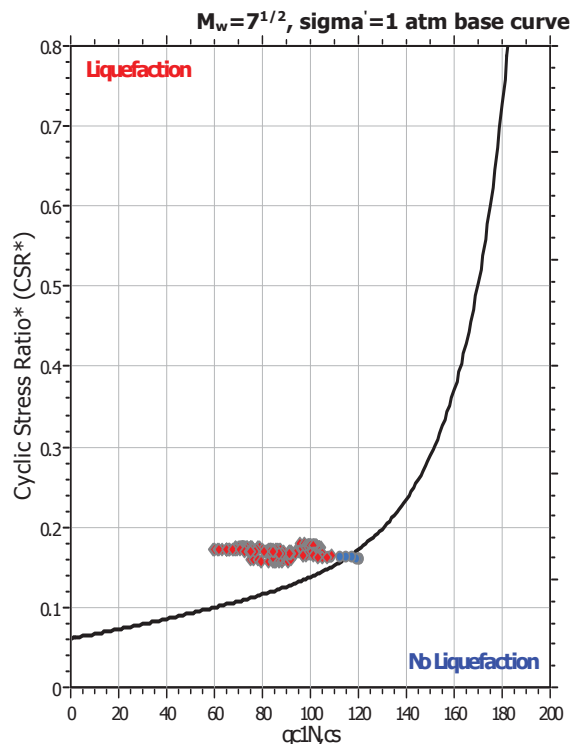
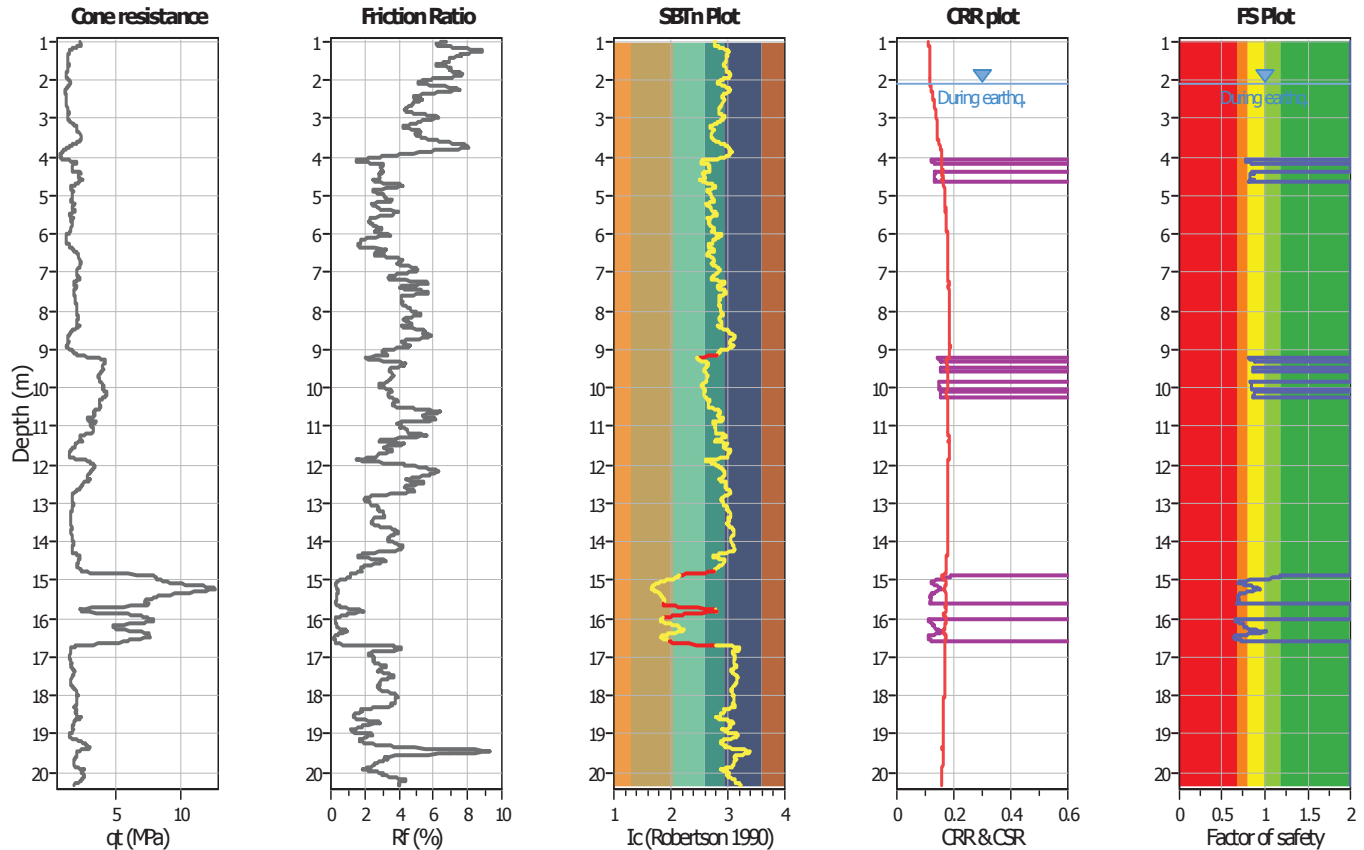
Project title : Studio del terreno di fondazione

Location : Fossoli, AIMAG

CPT file : CPTU1

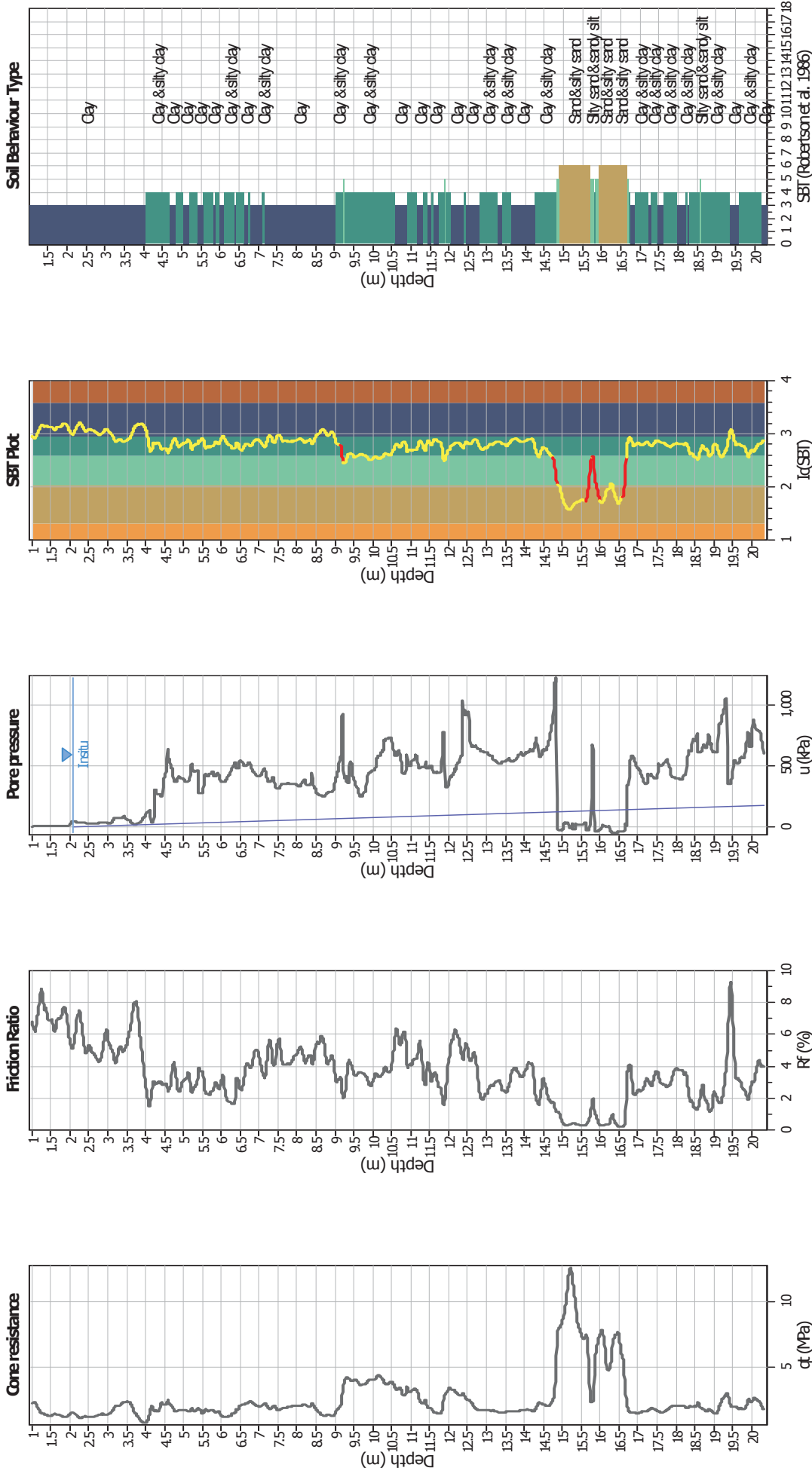
Input parameters and analysis data

| | | | | | | | |
|------------------------------|-------------------|---------------------------|--------------|-------------------------|-----|-----------------------------|------------|
| Analysis method: | B&I (2014) | G.W.T. (in-situ): | 2.10 m | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | B&I (2014) | G.W.T. (earthq.): | 2.10 m | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude M_w : | 6.14 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method |
| Peak ground acceleration: | 0.22 | Unit weight calculation: | Based on SBT | K_g applied: | Yes | | |



Zone A₁: Cyclic liquefaction likely depending on size and duration of cyclic loading
 Zone A₂: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
 Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
 Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



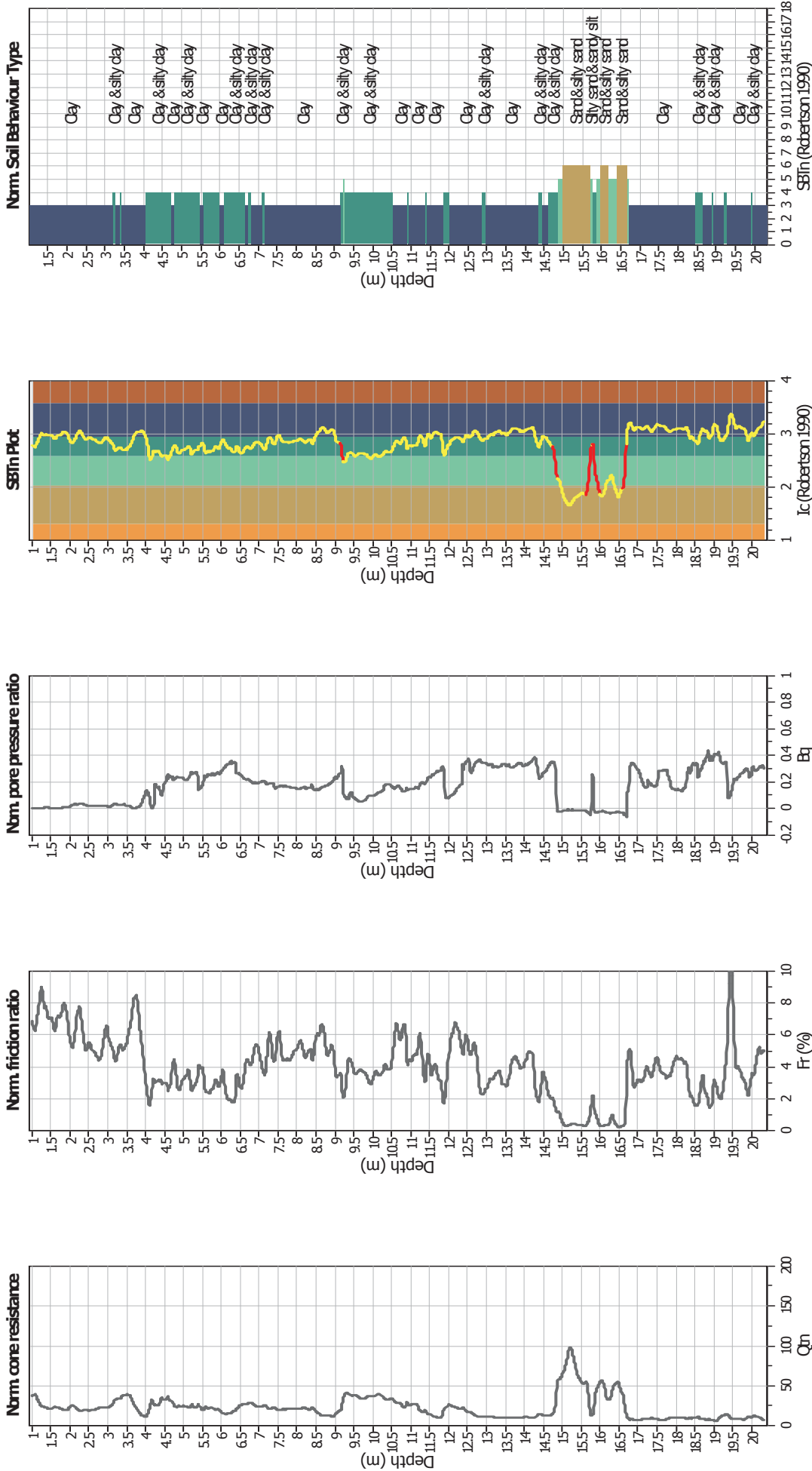
Input parameters and analysis data

| | | | | | |
|--------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K_{α} applied: | Yes |
| Earthquake magnitude M_w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

SBT legend

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

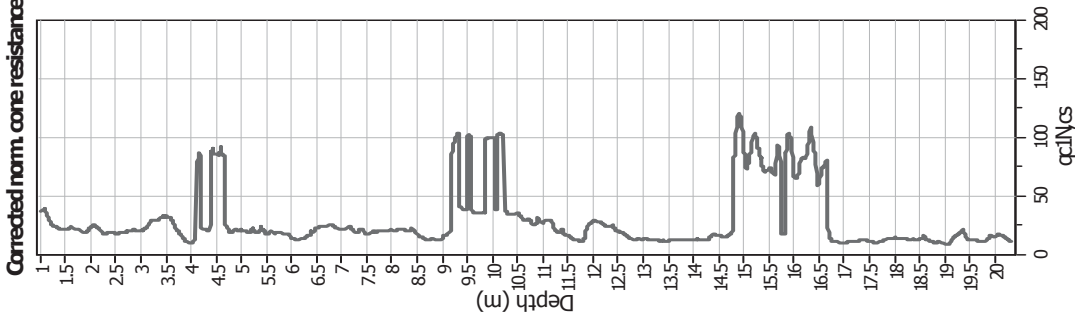
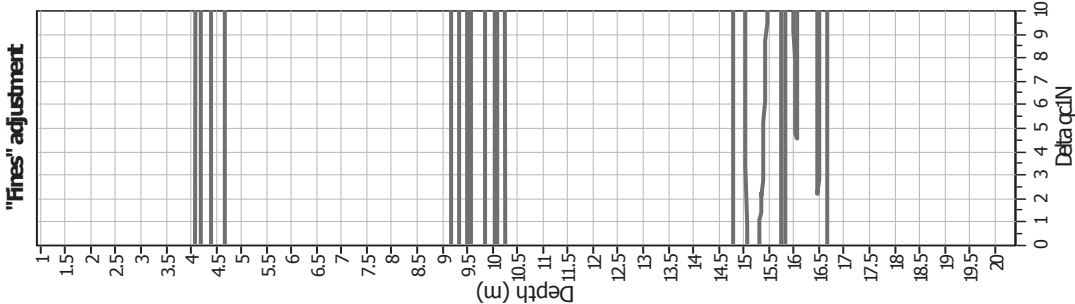
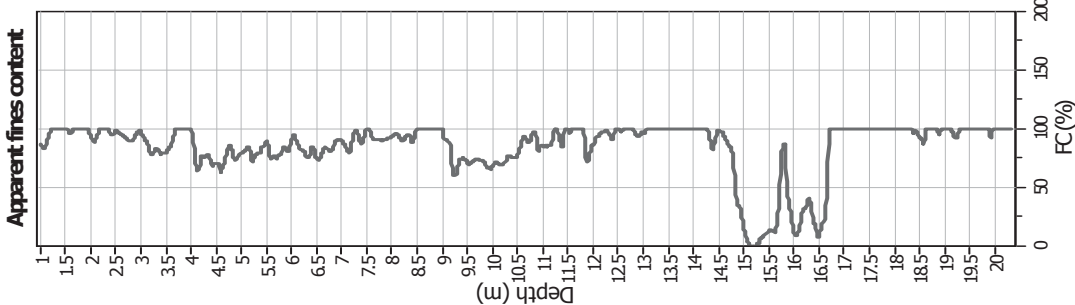
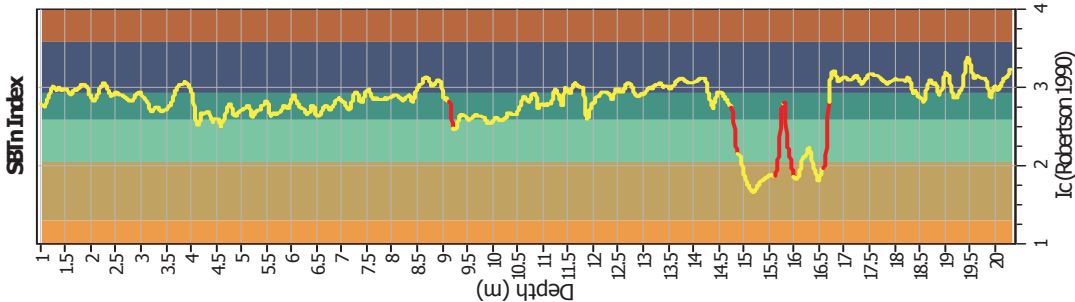
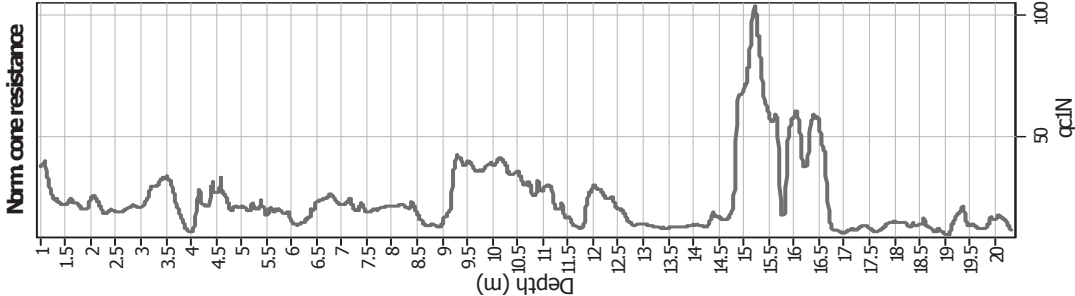
CPT basic interpretation plots (normalized)



Input parameters and analysis data

| | | | | | |
|--------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K_p applied: | Yes |
| Earthquake magnitude M_w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

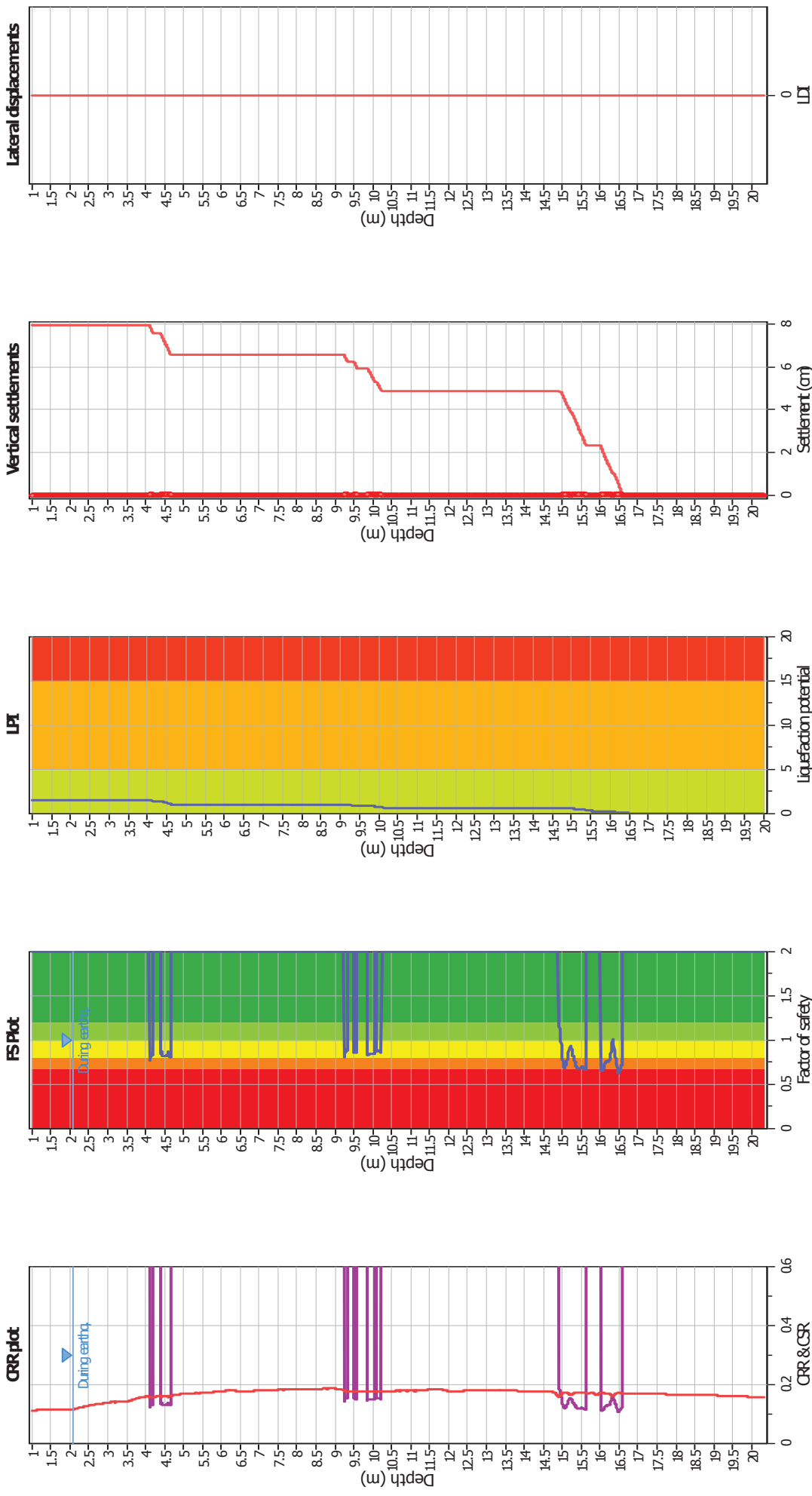
Liquefaction analysis overall plots (intermediate results)



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _{cs} applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

Liquefaction analysis overall plots



Input parameters and analysis data

| | |
|---------------------------------------|-------------------------------|
| Analysis method: | B&I (2014) |
| Fines correction method: | B&I (2014) |
| Points to test: | Based on I _c value |
| Earthquake magnitude M _w : | 6.14 |
| Peak ground acceleration: | 0.22 |
| Depth to water table (insitu): | 2.10 m |

| | |
|-------------------------------|--------------|
| Depth to GWT (earthq.): | 2.10 m |
| Average results interval: | 3 |
| I _c cut-off value: | 2.60 |
| Unit weight calculation: | Based on SBT |
| Use fill: | No |
| Fill height: | N/A |
| Fill weight: | N/A |
| Transition detect. applied: | Yes |
| K _s applied: | Yes |
| Clay like behavior applied: | Sands only |
| Limit depth applied: | No |
| Limit depth: | N/A |

F.S. color scheme

| | |
|---|----------------|
| Almost certain it will liquefy | Very high risk |
| Very likely to liquefy | High risk |
| Liquefaction and no liq. are equally likely | Low risk |
| Unlike to liquefy | |
| Almost certain it will not liquefy | |

LPI color scheme

| |
|----------------|
| Very high risk |
| High risk |
| Low risk |

LIQUEFACTION ANALYSIS REPORT

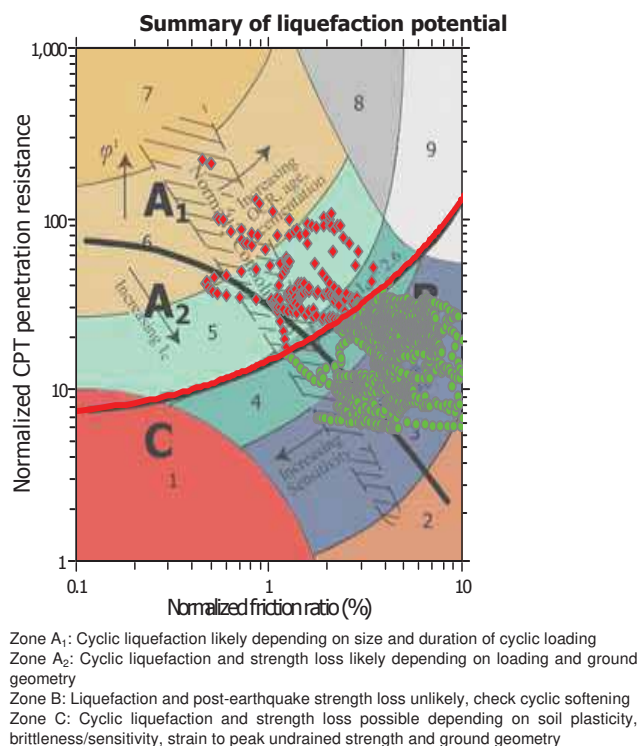
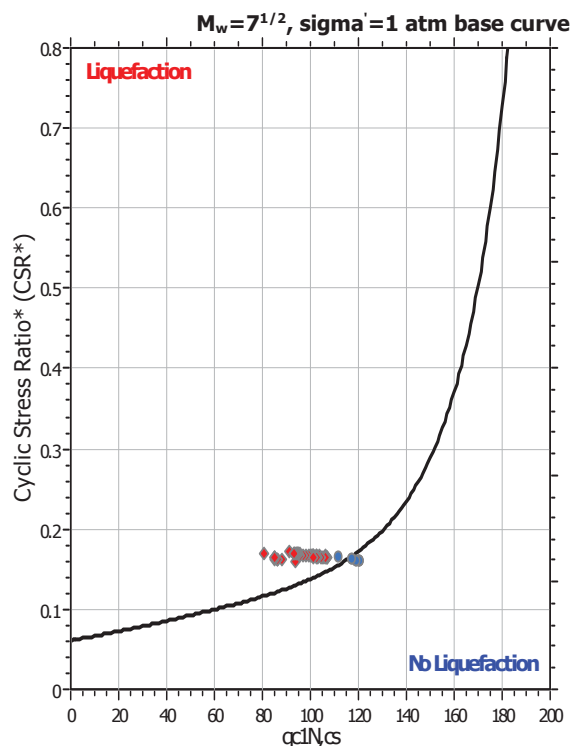
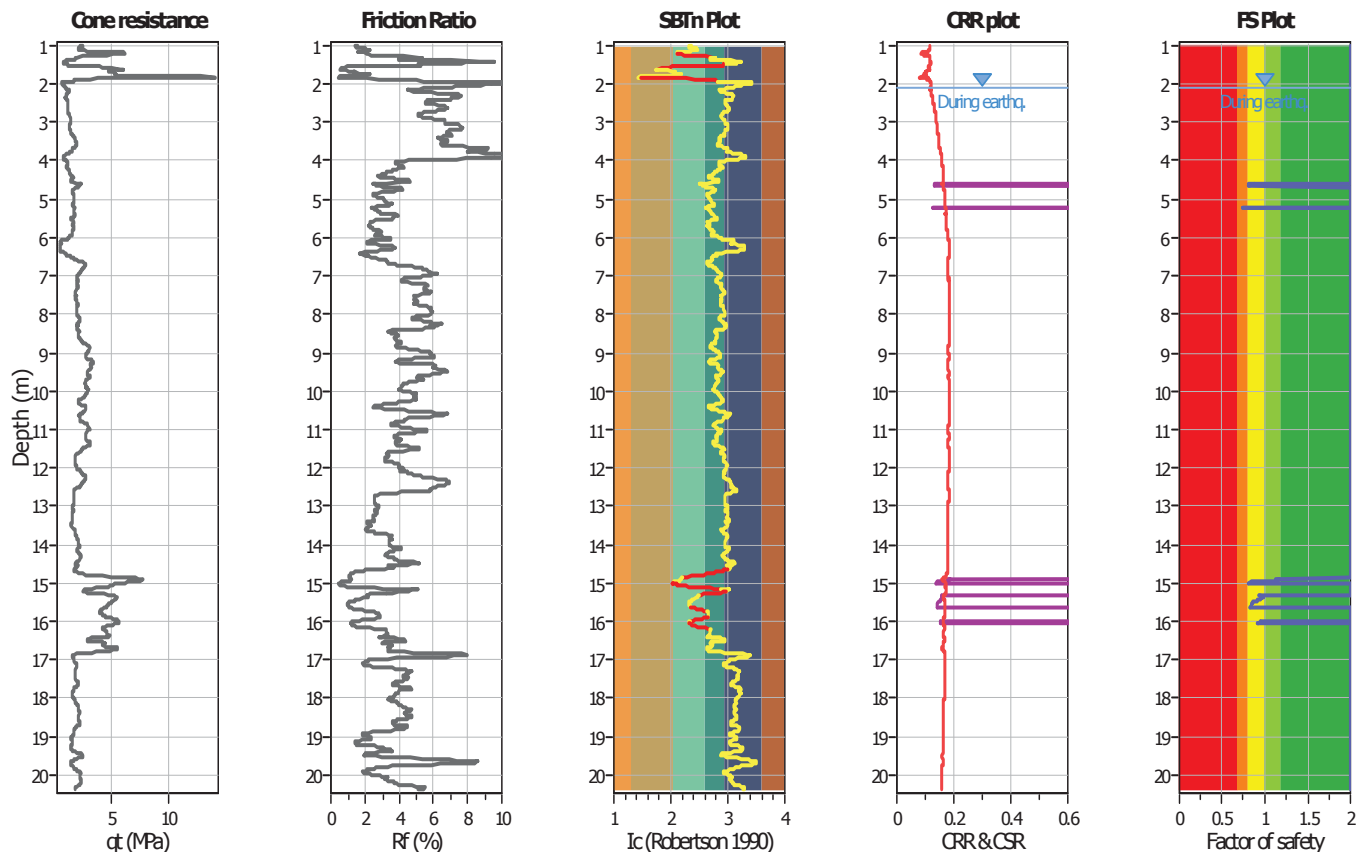
Project title : Studio del terreno di fondazione

Location : Fossoli, AIMAG

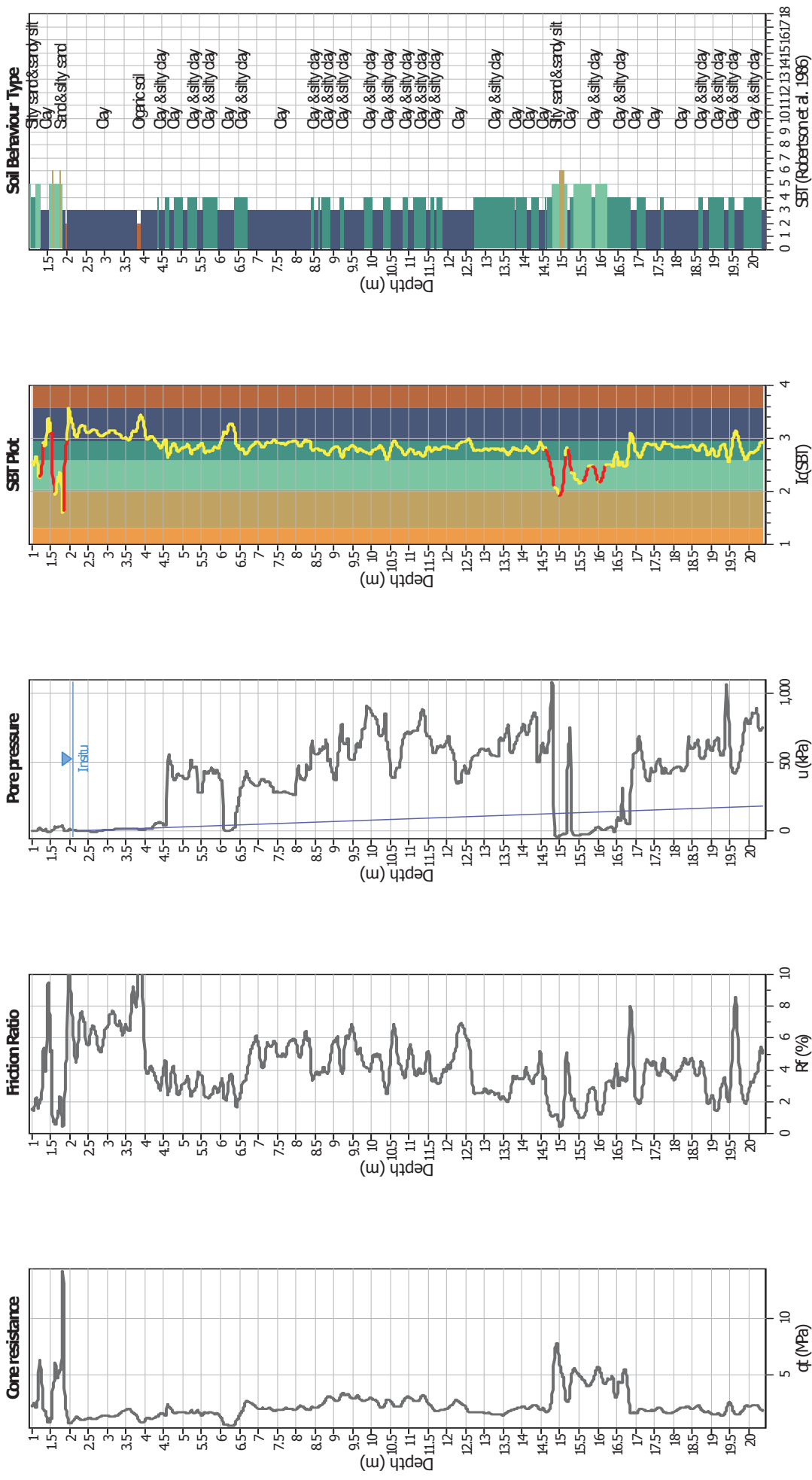
CPT file : CPTU2

Input parameters and analysis data

| | | | | | | | |
|------------------------------|-------------------|---------------------------|--------------|-------------------------|-----|----------------------|------------|
| Analysis method: | B&I (2014) | G.W.T. (in-situ): | 2.10 m | Use fill: | No | Clay like behavior | |
| Fines correction method: | B&I (2014) | G.W.T. (earthq.): | 2.10 m | Fill height: | N/A | applied: | Sands only |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth applied: | No |
| Earthquake magnitude M_w : | 6.14 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | Limit depth: | N/A |
| Peak ground acceleration: | 0.22 | Unit weight calculation: | Based on SBT | K_g applied: | Yes | MSF method: | Method |



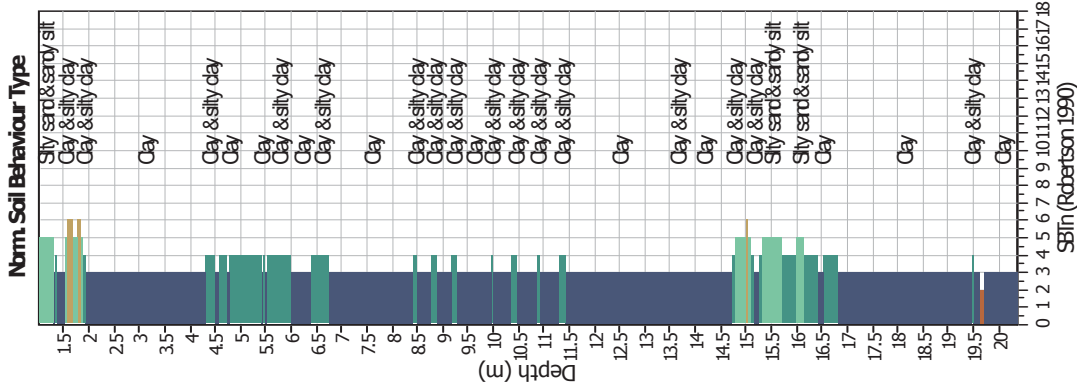
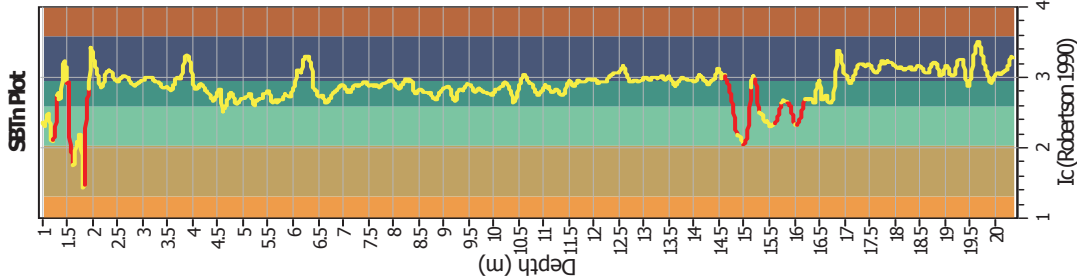
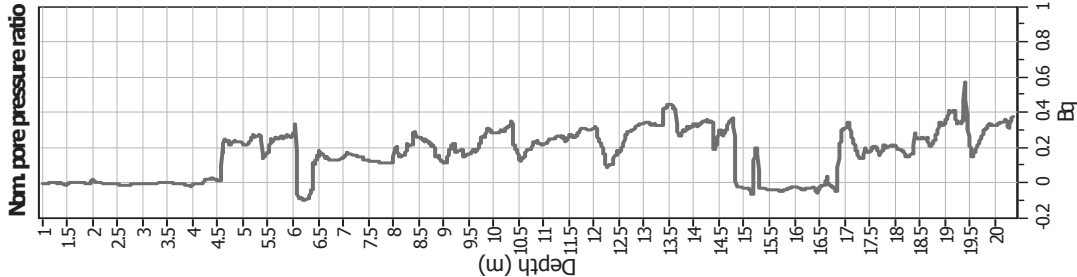
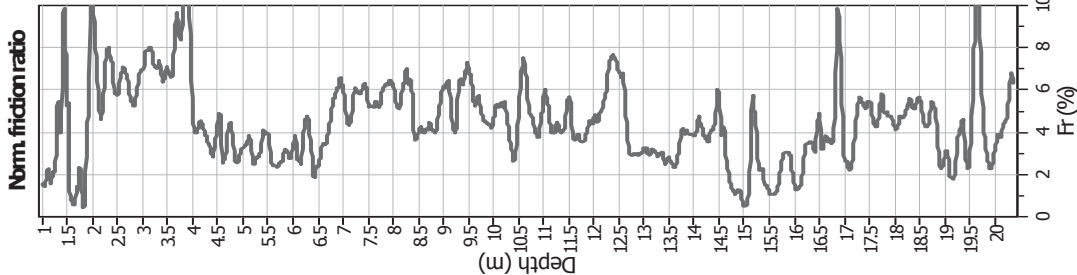
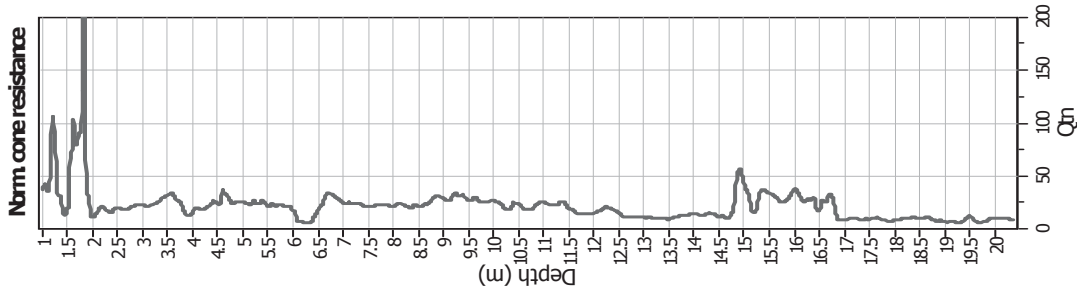
CPT basic interpretation plots



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _u applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

CPT basic interpretation plots (normalized)



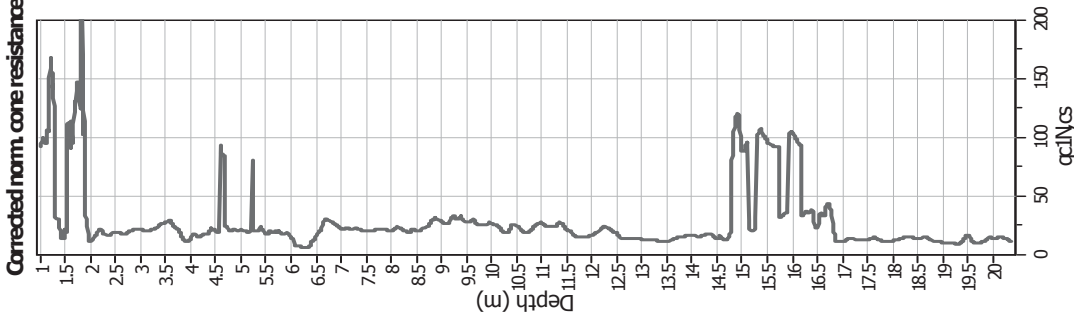
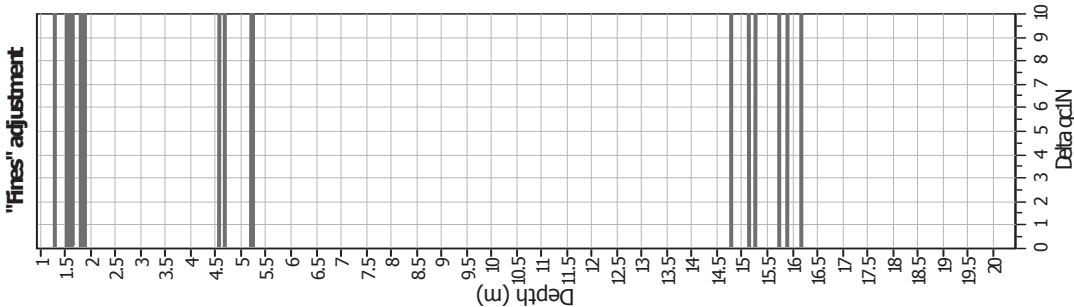
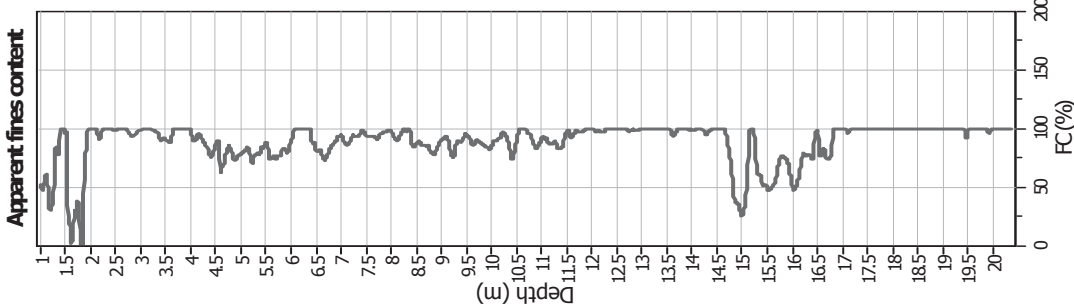
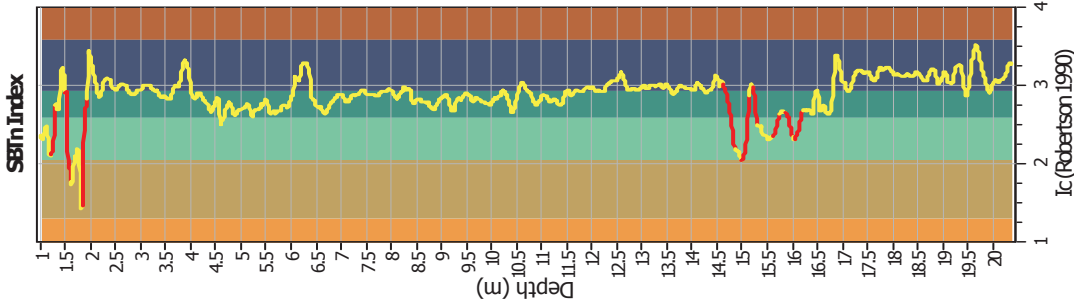
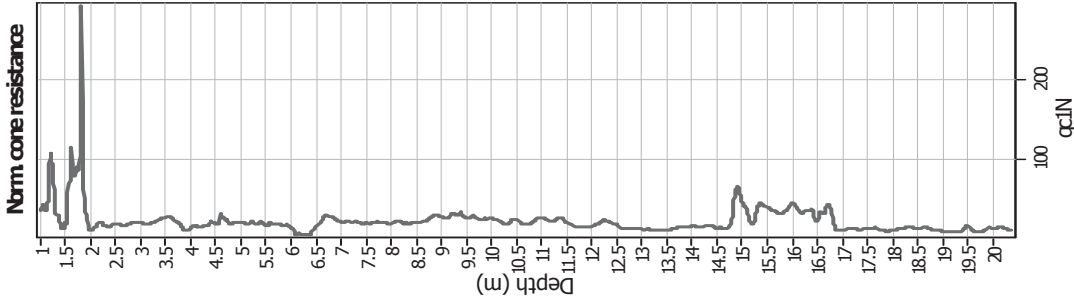
Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _u applied: | Sands only |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | No | Clay like behavior applied: | No |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | N/A |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

SBTn legend

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

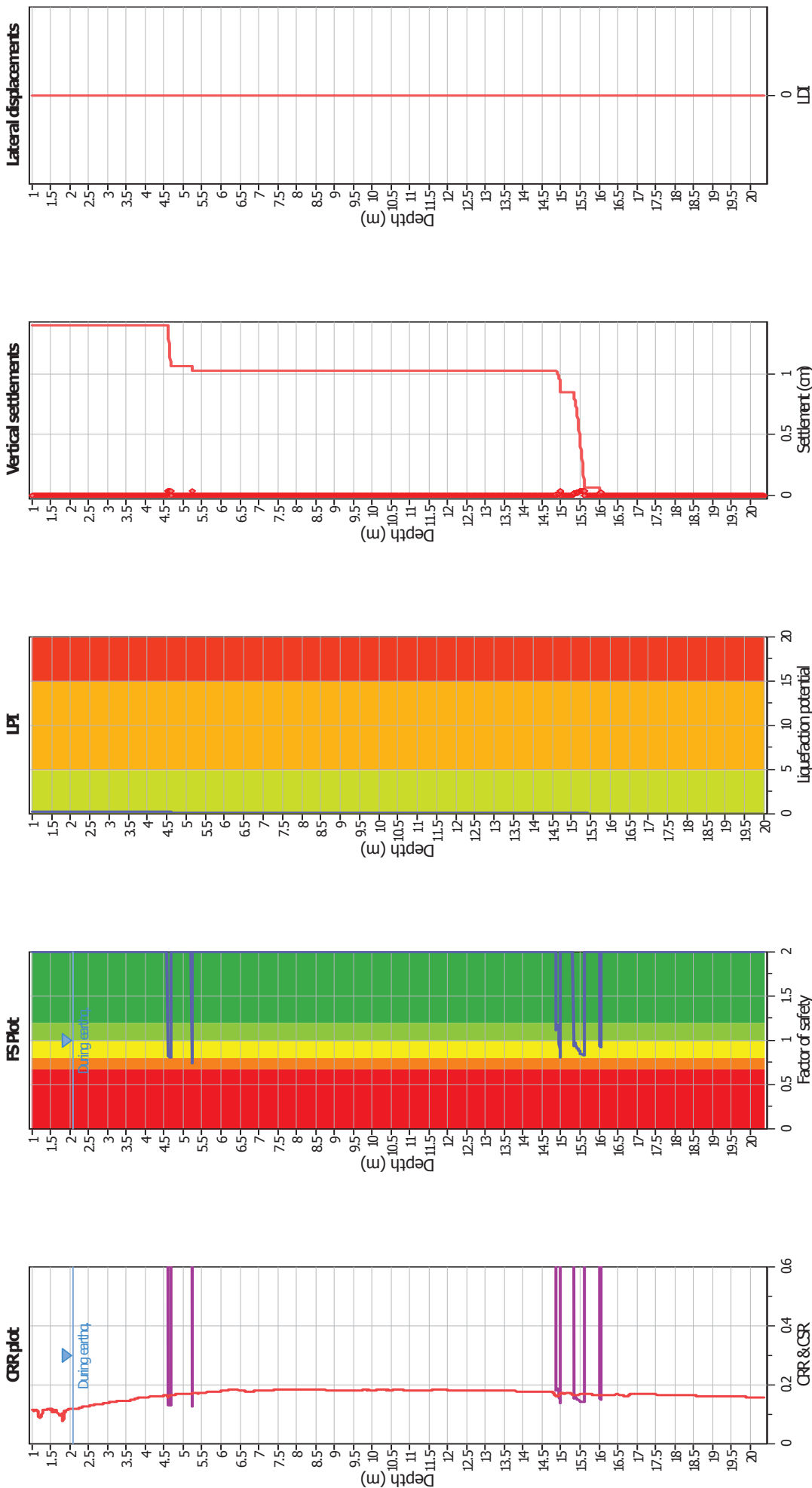
Liquefaction analysis overall plots (intermediate results)



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------------------|-------------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on I _c value | I _c cut-off value: | 2.60 | K _{cs} applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

Liquefaction analysis overall plots



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (earthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _s applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

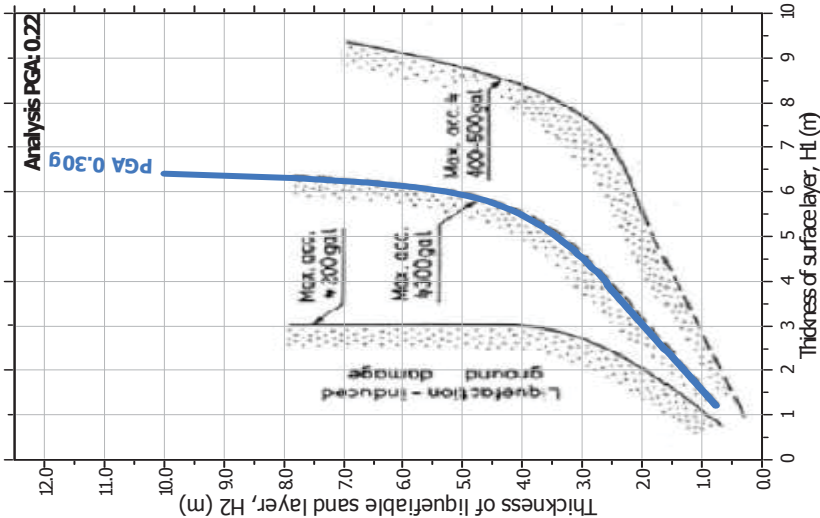
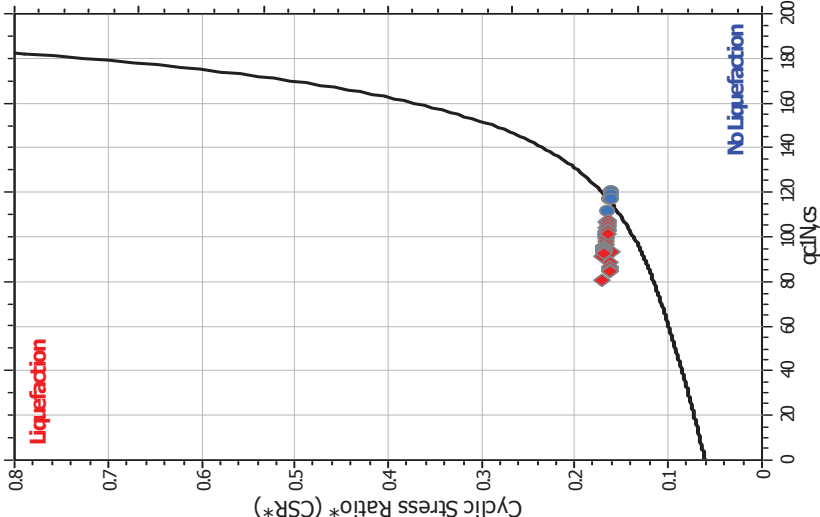
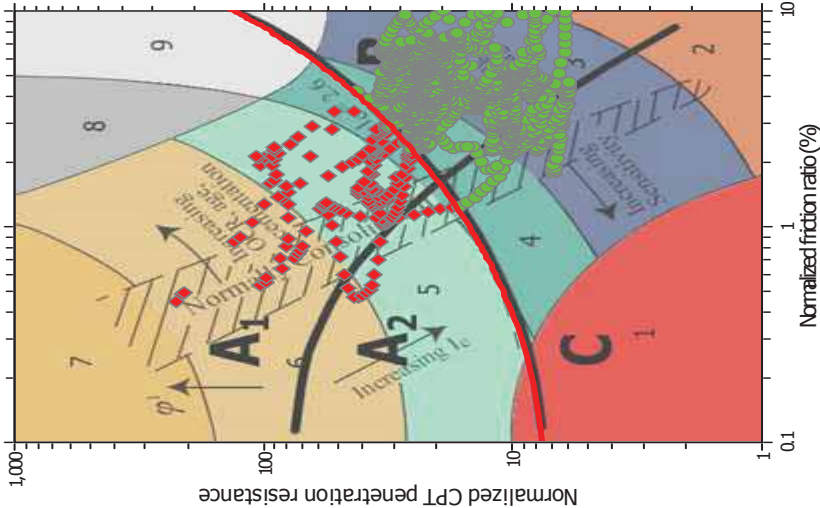
F.S. color scheme

| | | | | |
|--------------------------------|------------------------|---|-------------------|------------------------------------|
| Almost certain it will liquefy | Very likely to liquefy | Liquefaction and no liq. are equally likely | Unlike to liquefy | Almost certain it will not liquefy |
| Red | Orange | Yellow | Green | Dark Green |

LPI color scheme

| | | |
|----------------|-----------|----------|
| Very high risk | High risk | Low risk |
| Red | Orange | Green |

Liquefaction analysis summary plots



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _u applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

LIQUEFACTION ANALYSIS REPORT

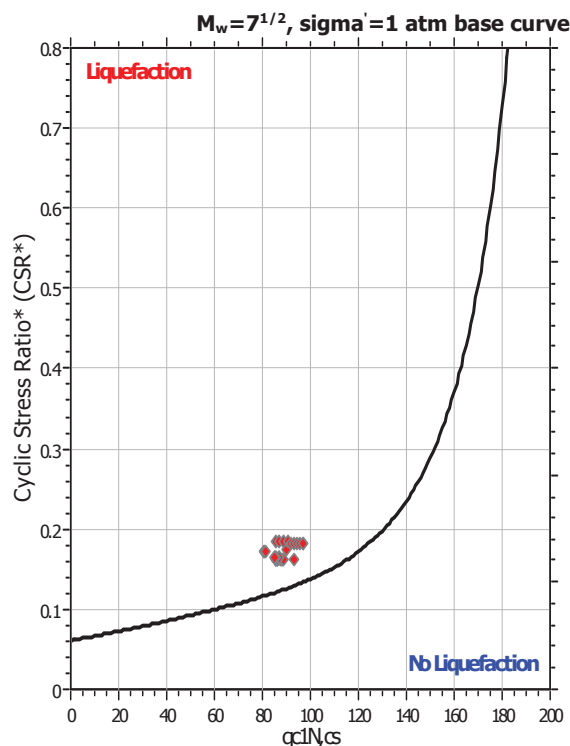
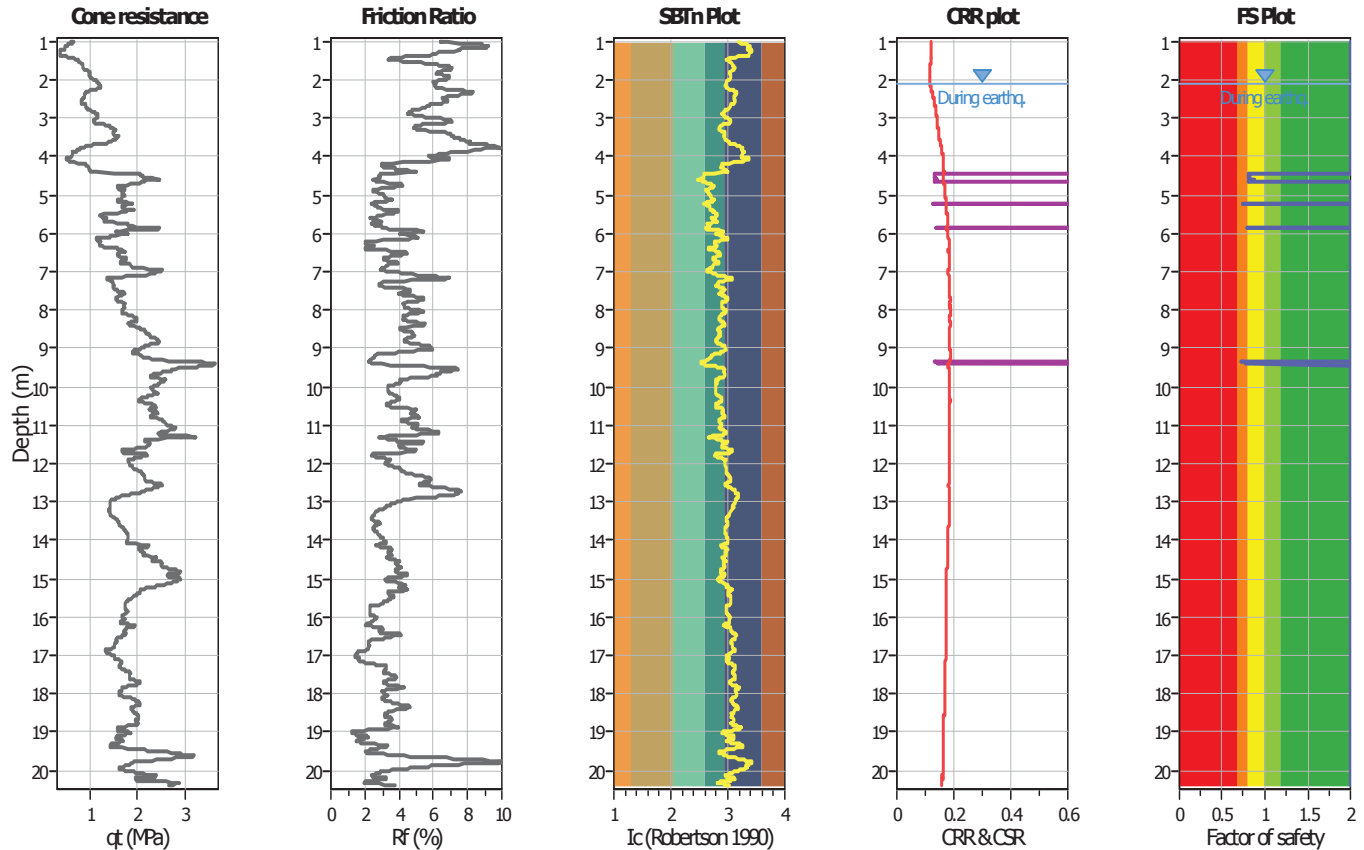
Project title : Studio del terreno di fondazione

Location : Fossoli, AIMAG

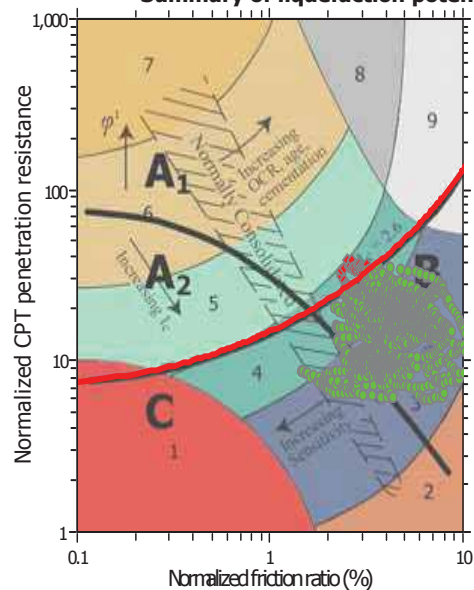
CPT file : CPTU3

Input parameters and analysis data

| | | | | | | | |
|------------------------------|-------------------|---------------------------|--------------|-------------------------|-----|-----------------------------|------------|
| Analysis method: | B&I (2014) | G.W.T. (in-situ): | 2.10 m | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | B&I (2014) | G.W.T. (earthq.): | 2.10 m | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude M_w : | 6.14 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method |
| Peak ground acceleration: | 0.22 | Unit weight calculation: | Based on SBT | K_g applied: | Yes | | |

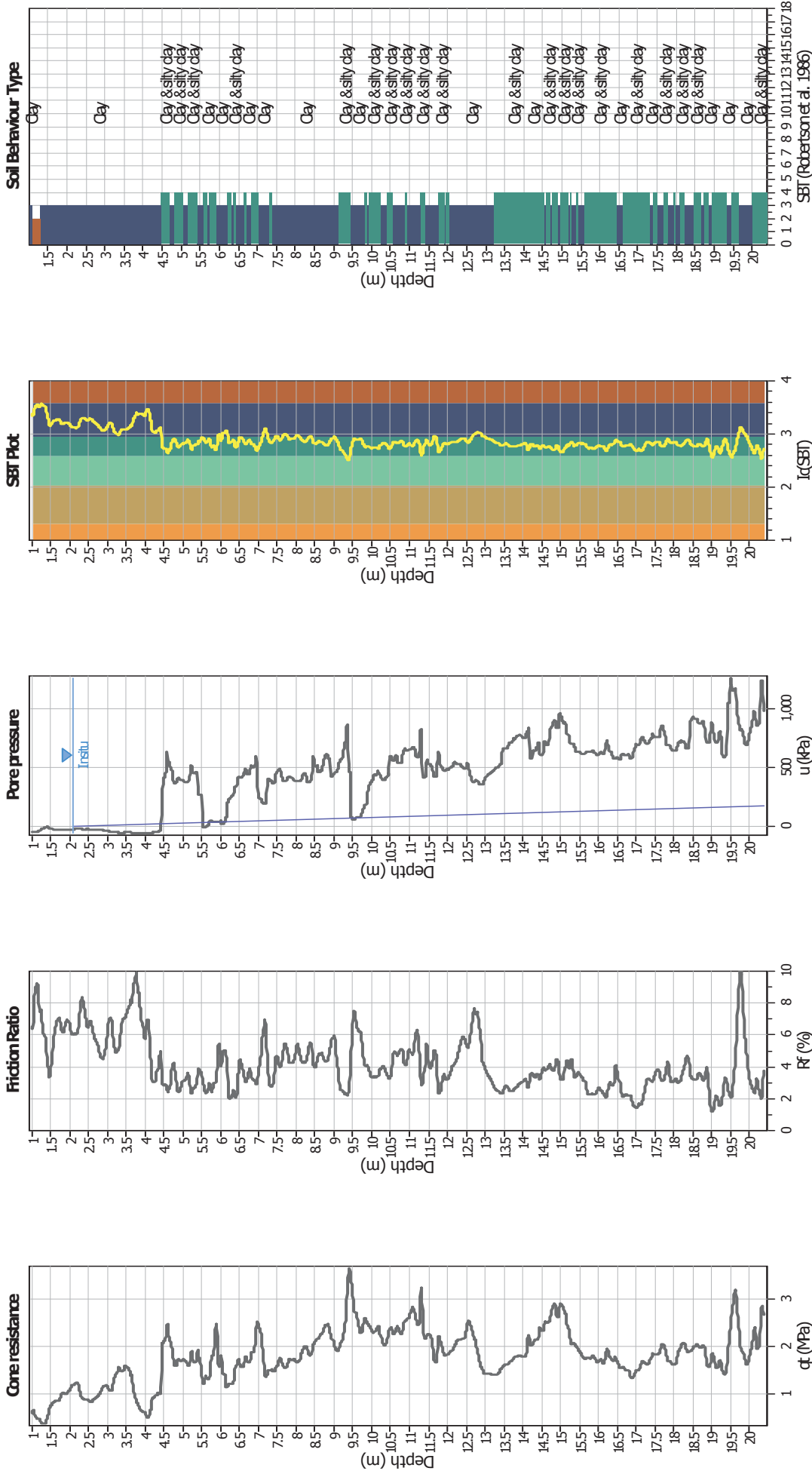


Summary of liquefaction potential



Zone A₁: Cyclic liquefaction likely depending on size and duration of cyclic loading
 Zone A₂: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
 Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
 Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

CPT basic interpretation plots



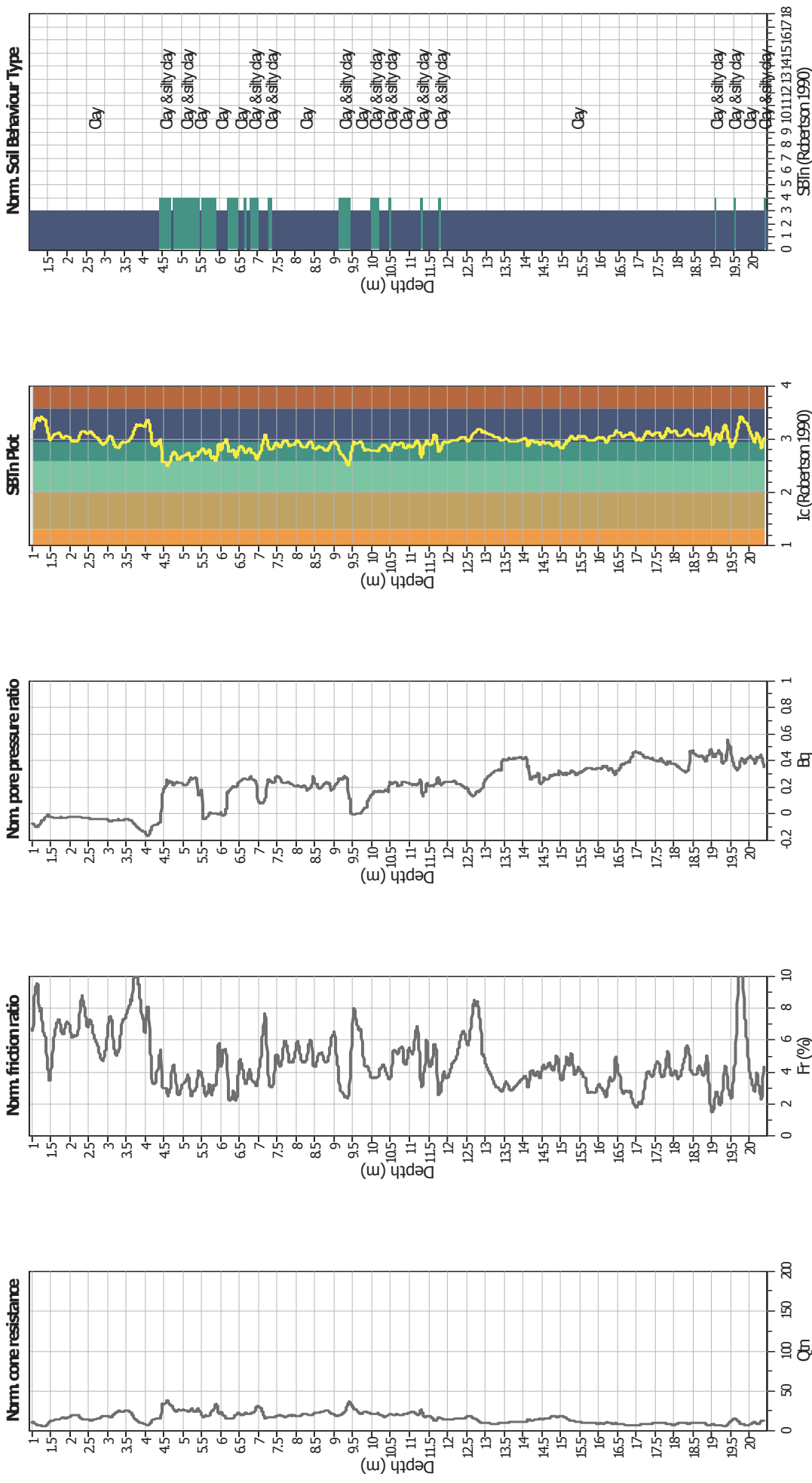
Input parameters and analysis data

| | | | | | |
|--------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K_{α} applied: | Yes |
| Earthquake magnitude M_w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

SBT legend

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

CPT basic interpretation plots (normalized)



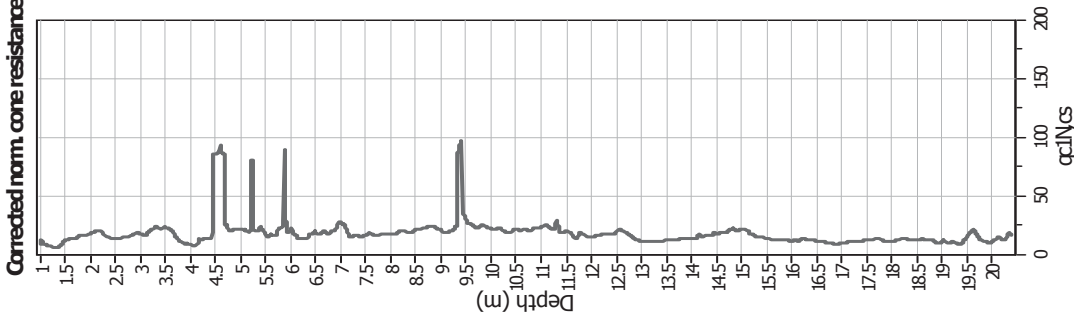
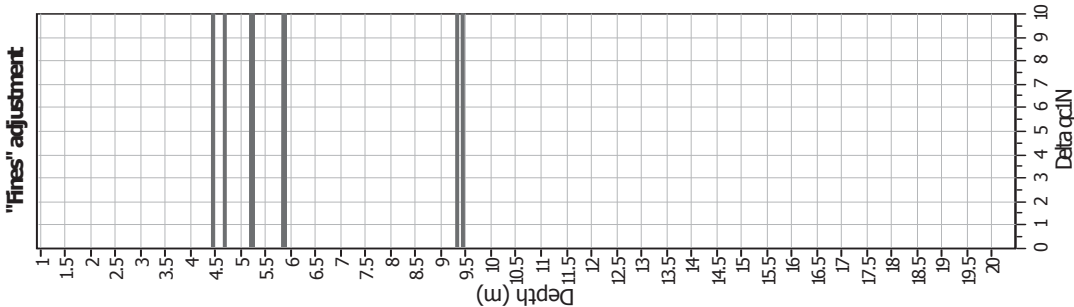
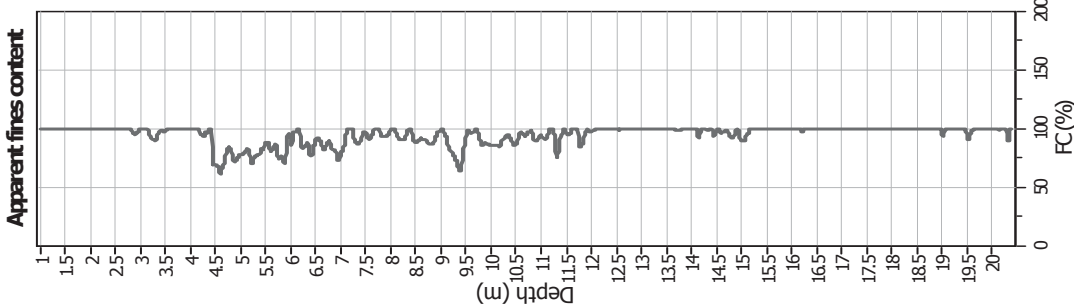
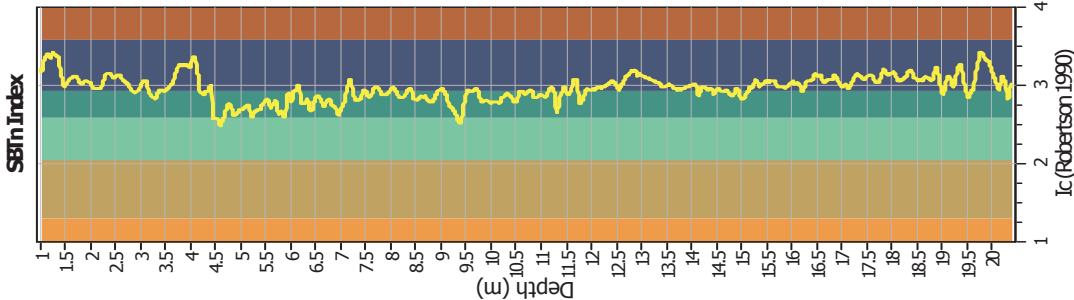
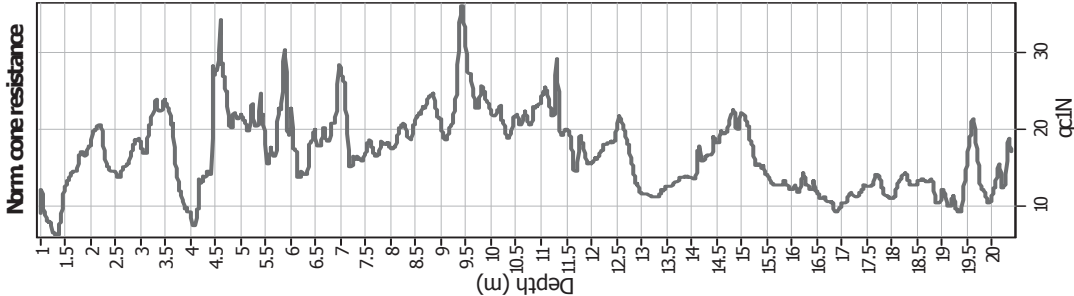
Input parameters and analysis data

| | | | | | |
|--------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K_p applied: | Yes |
| Earthquake magnitude M_w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

SBTn legend

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

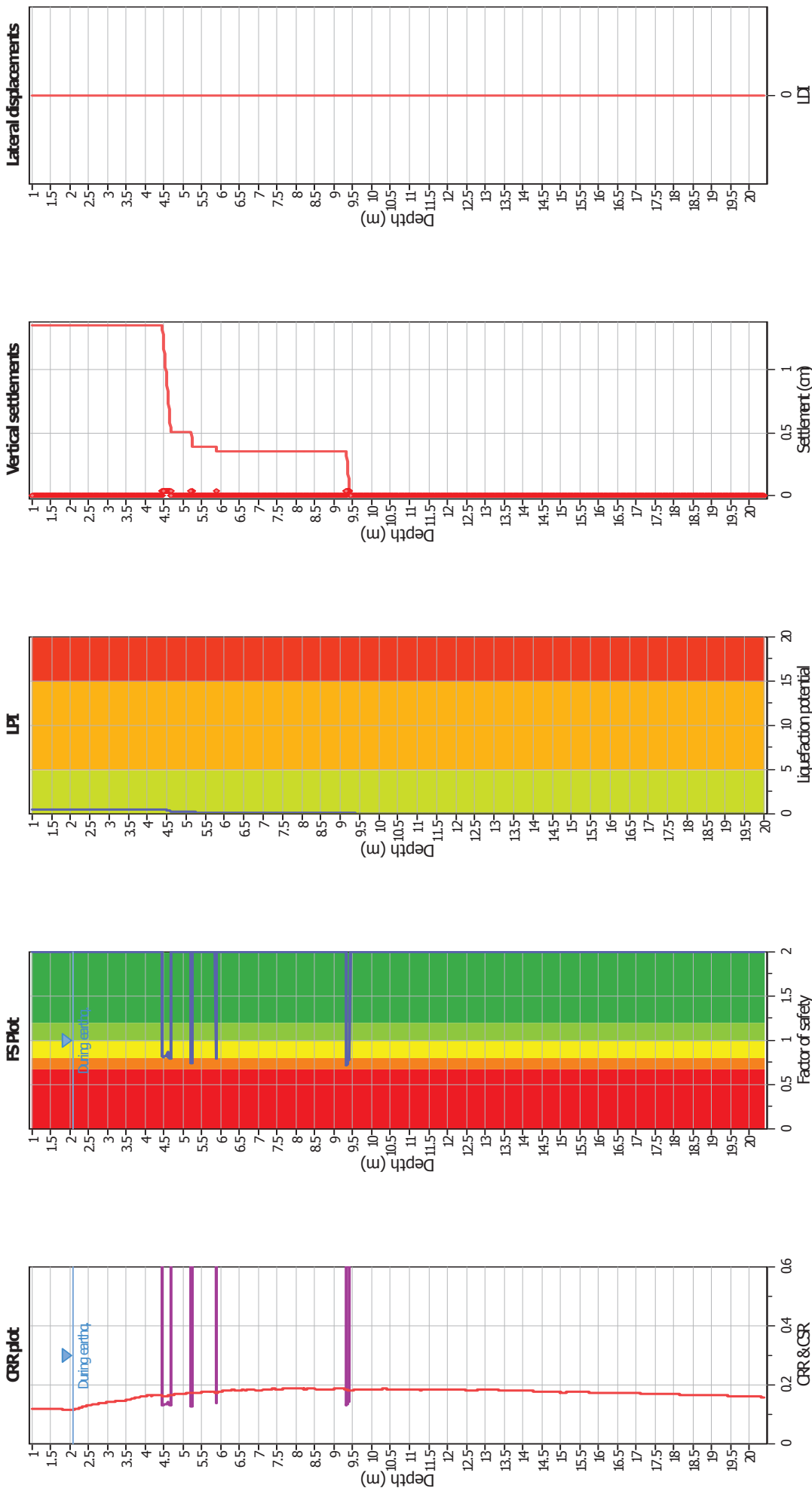
Liquefaction analysis overall plots (intermediate results)



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _{cs} applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

Liquefaction analysis overall plots



Input parameters and analysis data

| | |
|--------------------------------|-------------------|
| Analysis method: | B&I (2014) |
| Fines correction method: | B&I (2014) |
| Points to test: | Based on Ic value |
| Earthquake magnitude M_w : | 6.14 |
| Peak ground acceleration: | 0.22 |
| Depth to water table (insitu): | 2.10 m |

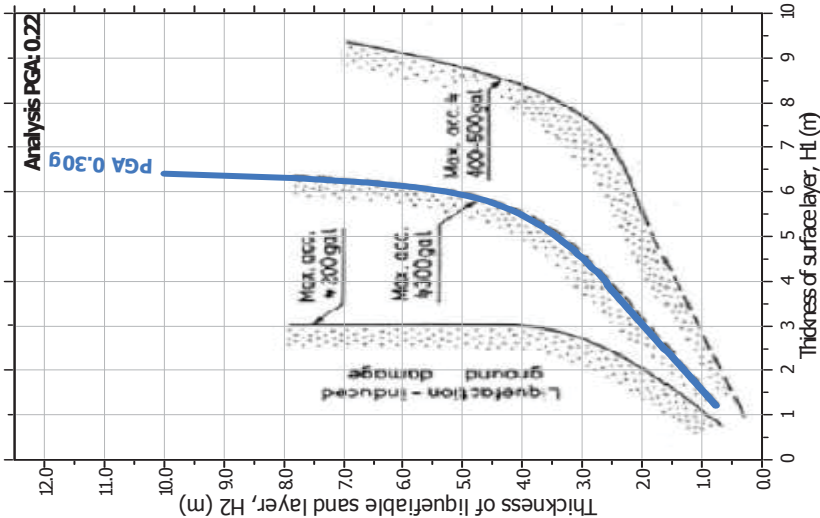
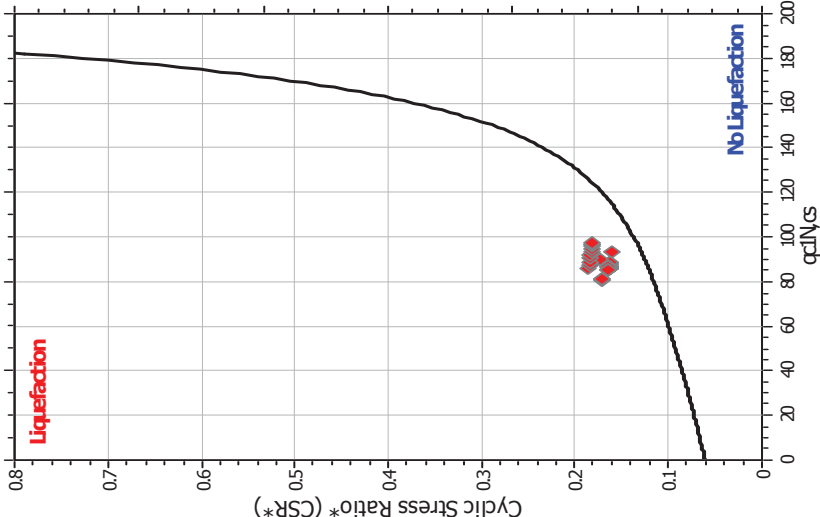
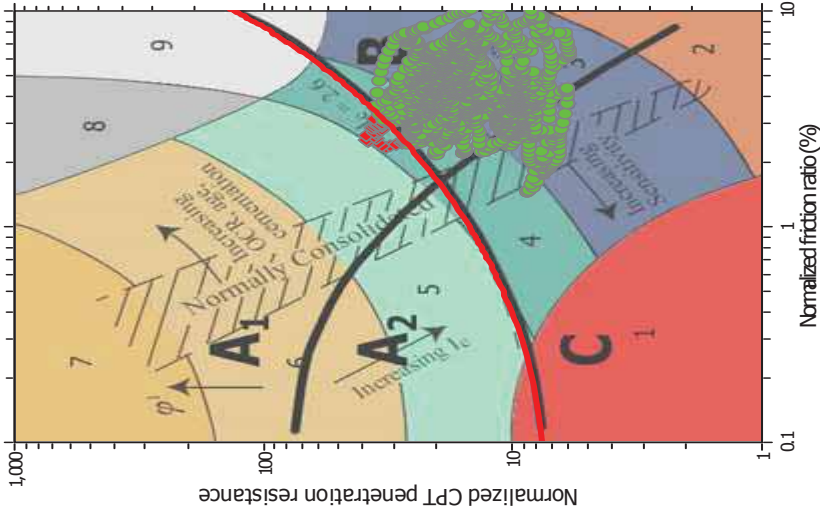
F.S. color scheme

| | |
|---|----------------|
| Almost certain it will liquefy | Very high risk |
| Very likely to liquefy | High risk |
| Liquefaction and no liq. are equally likely | Low risk |
| Unlike to liquefy | |
| Almost certain it will not liquefy | |

LPI color scheme

| |
|----------------|
| Very high risk |
| High risk |
| Low risk |

Liquefaction analysis summary plots



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _u applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

LIQUEFACTION ANALYSIS REPORT

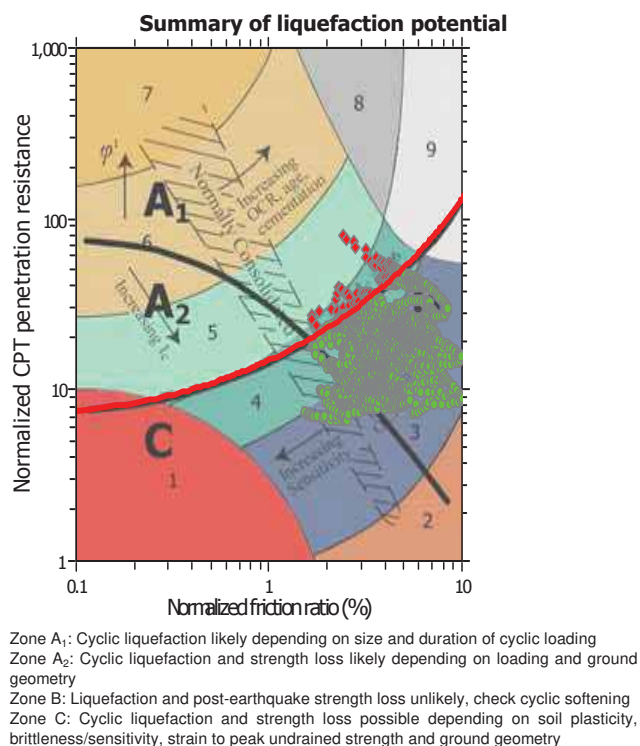
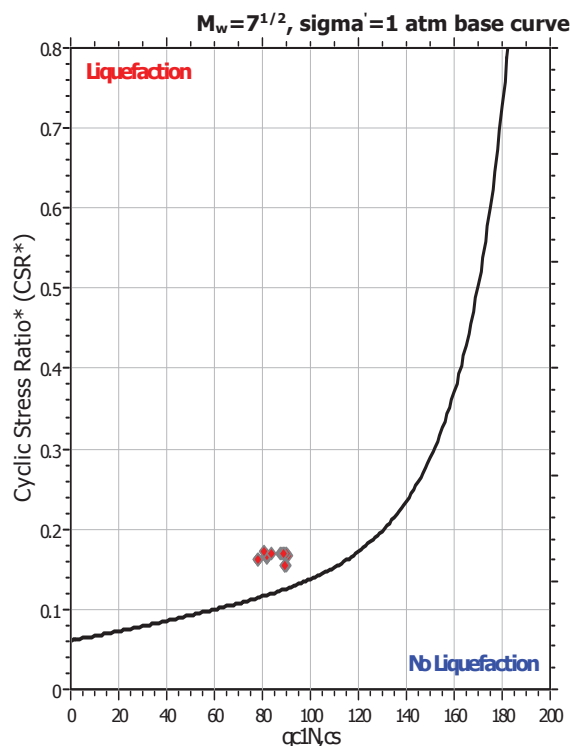
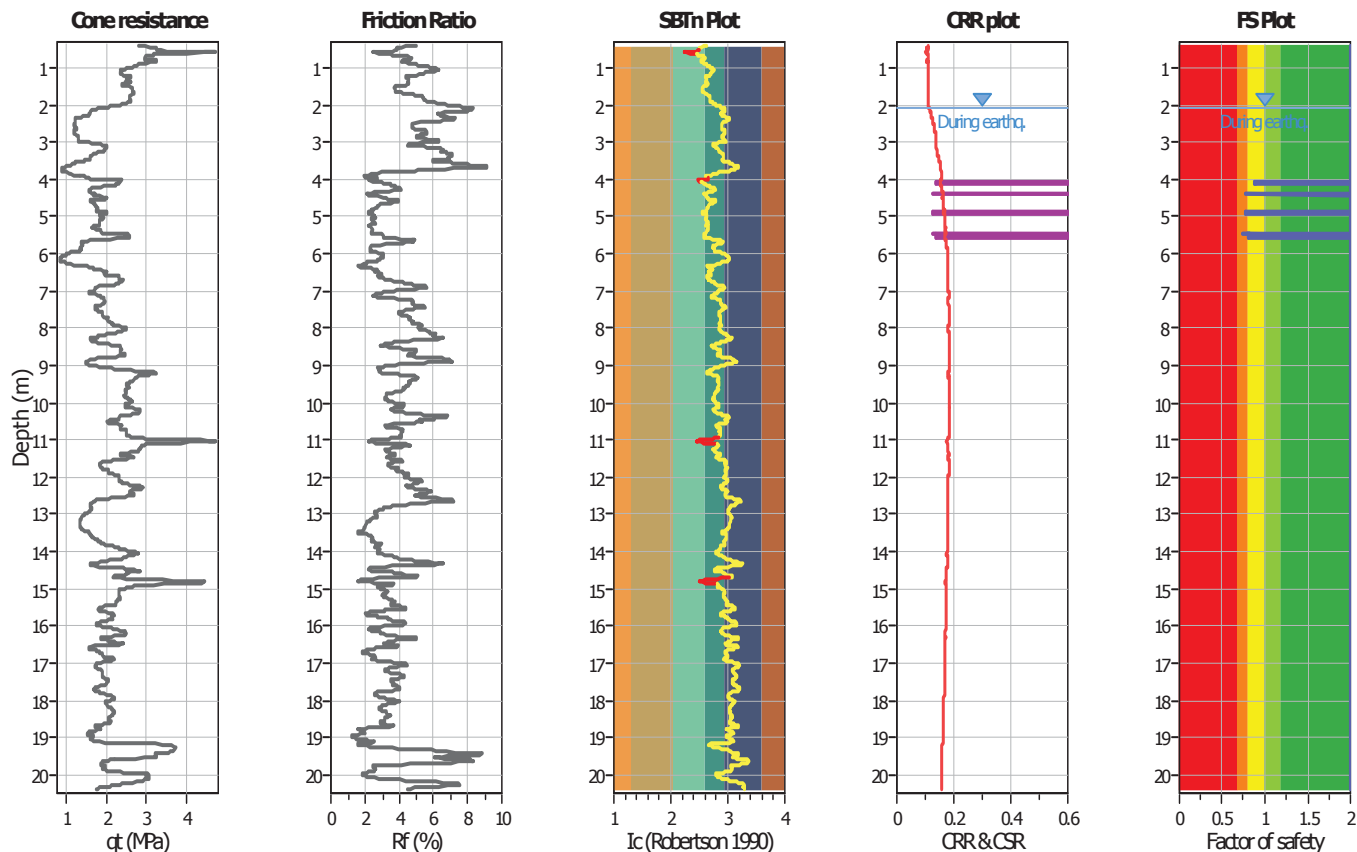
Project title : Studio del terreno di fondazione

Location : Fossoli, AIMAG

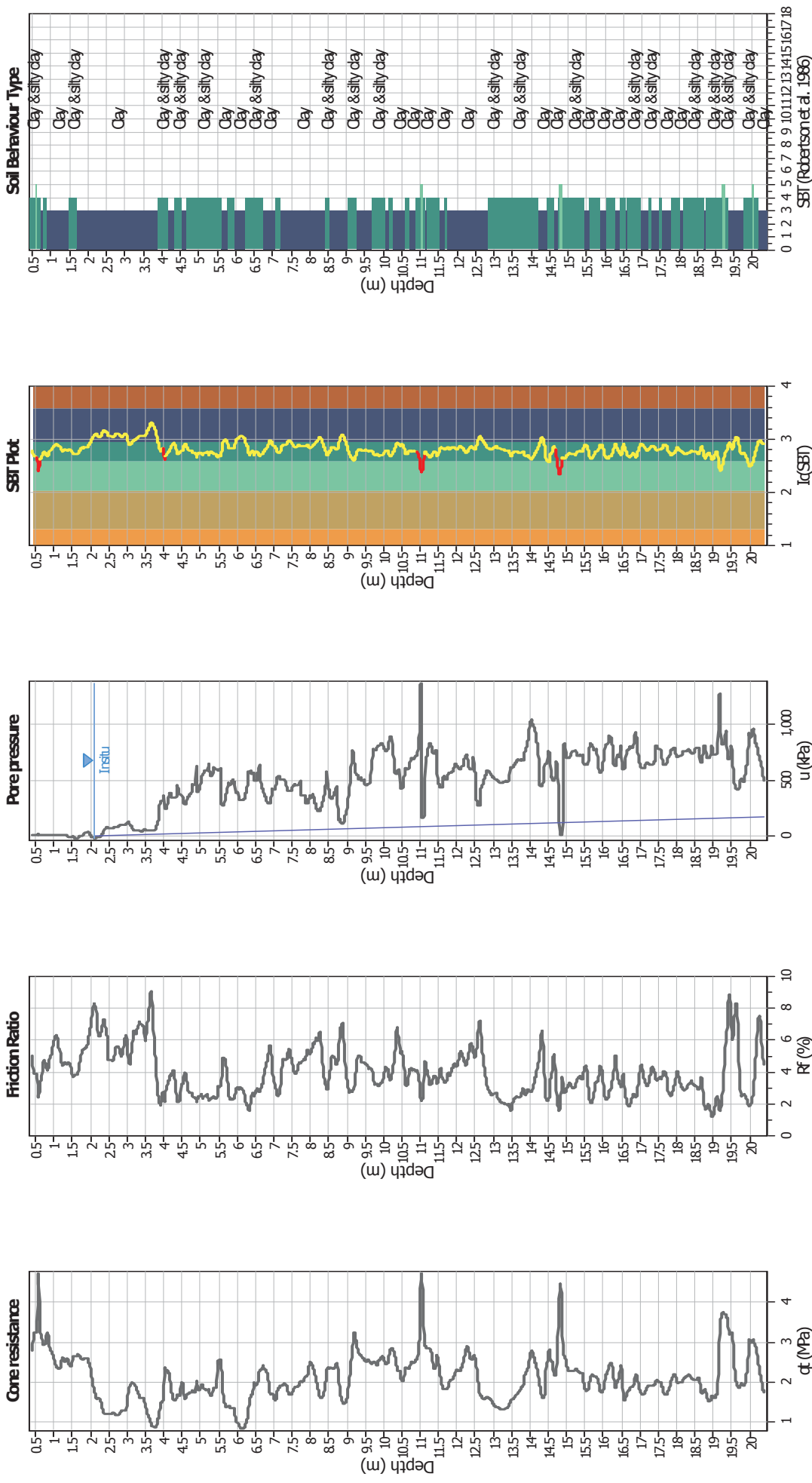
CPT file : CPTU4

Input parameters and analysis data

| | | | | | | | |
|------------------------------|-------------------|---------------------------|--------------|-------------------------|-----|-----------------------------|------------|
| Analysis method: | B&I (2014) | G.W.T. (in-situ): | 2.10 m | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | B&I (2014) | G.W.T. (earthq.): | 2.10 m | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude M_w : | 6.14 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method |
| Peak ground acceleration: | 0.22 | Unit weight calculation: | Based on SBT | K_g applied: | Yes | | |



CPT basic interpretation plots



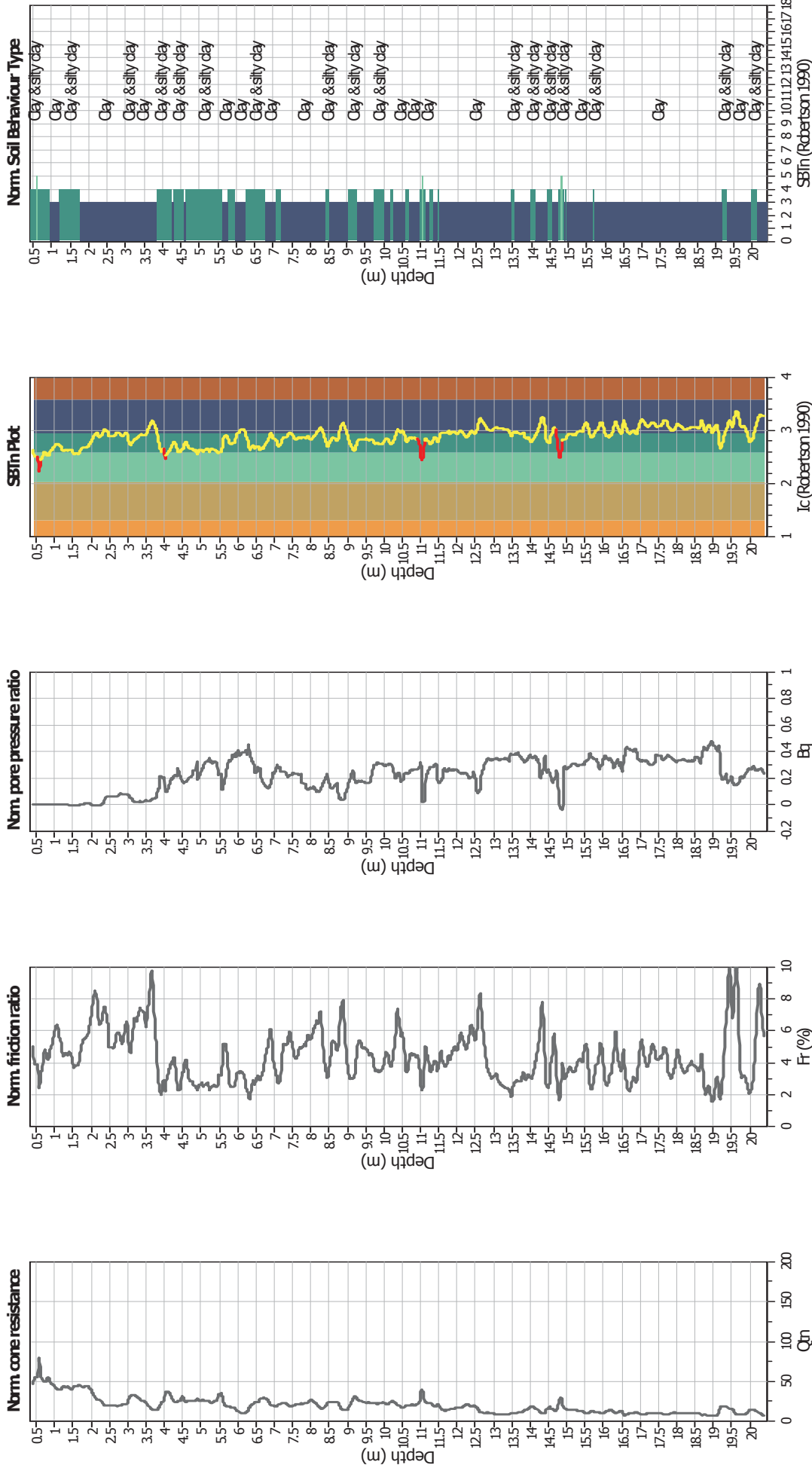
Input parameters and analysis data

| | | | | | |
|--------------------------------|----------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on I_c value | I_c cut-off value: | 2.60 | K_{α} applied: | Yes |
| Earthquake magnitude M_w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

SBT legend

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

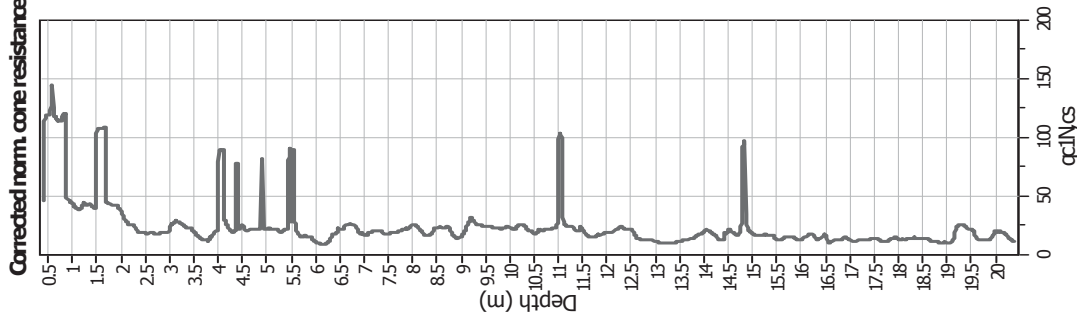
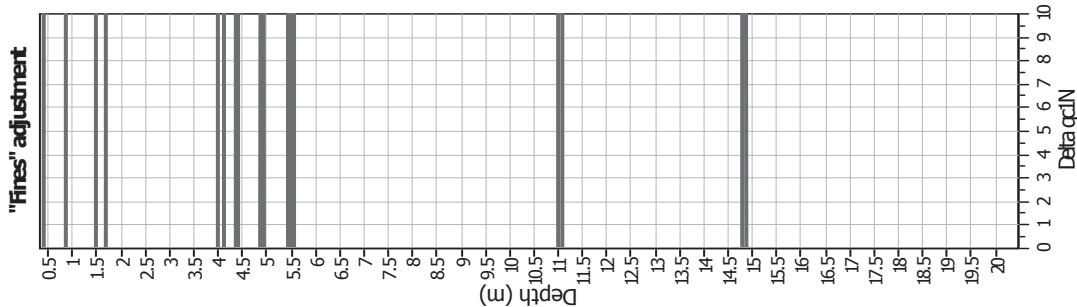
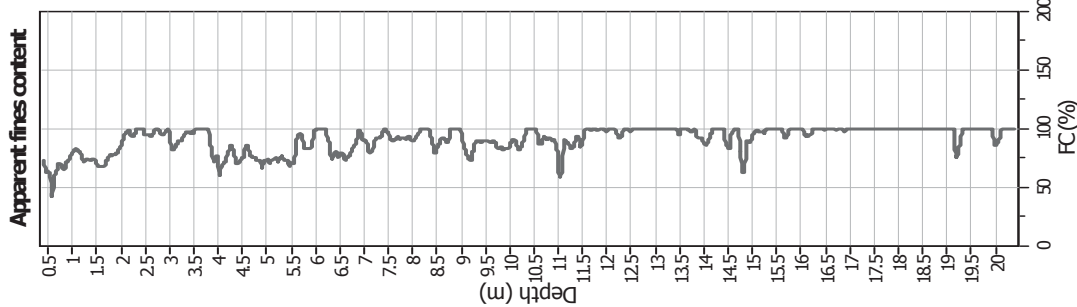
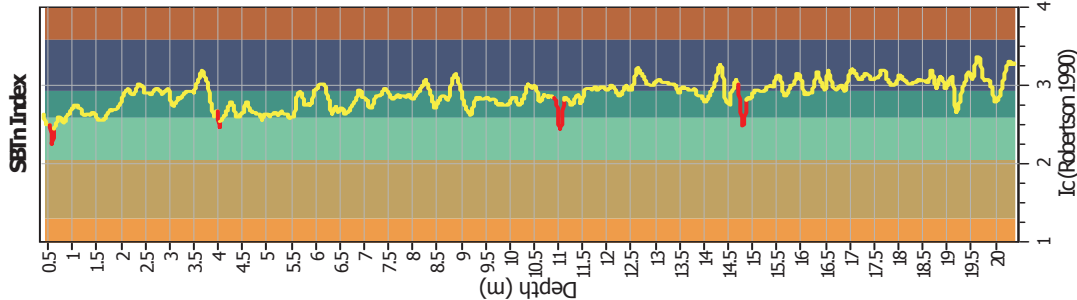
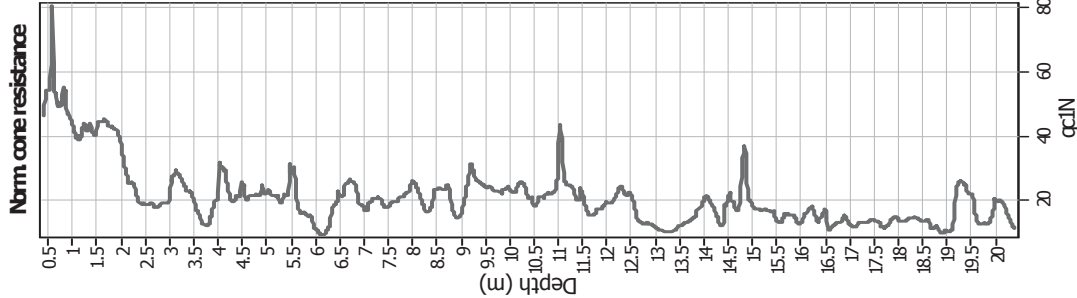
CPT basic interpretation plots (normalized)



Input parameters and analysis data

| | | | | | |
|--------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K_p applied: | Sands only |
| Earthquake magnitude M_w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | No |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | N/A |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

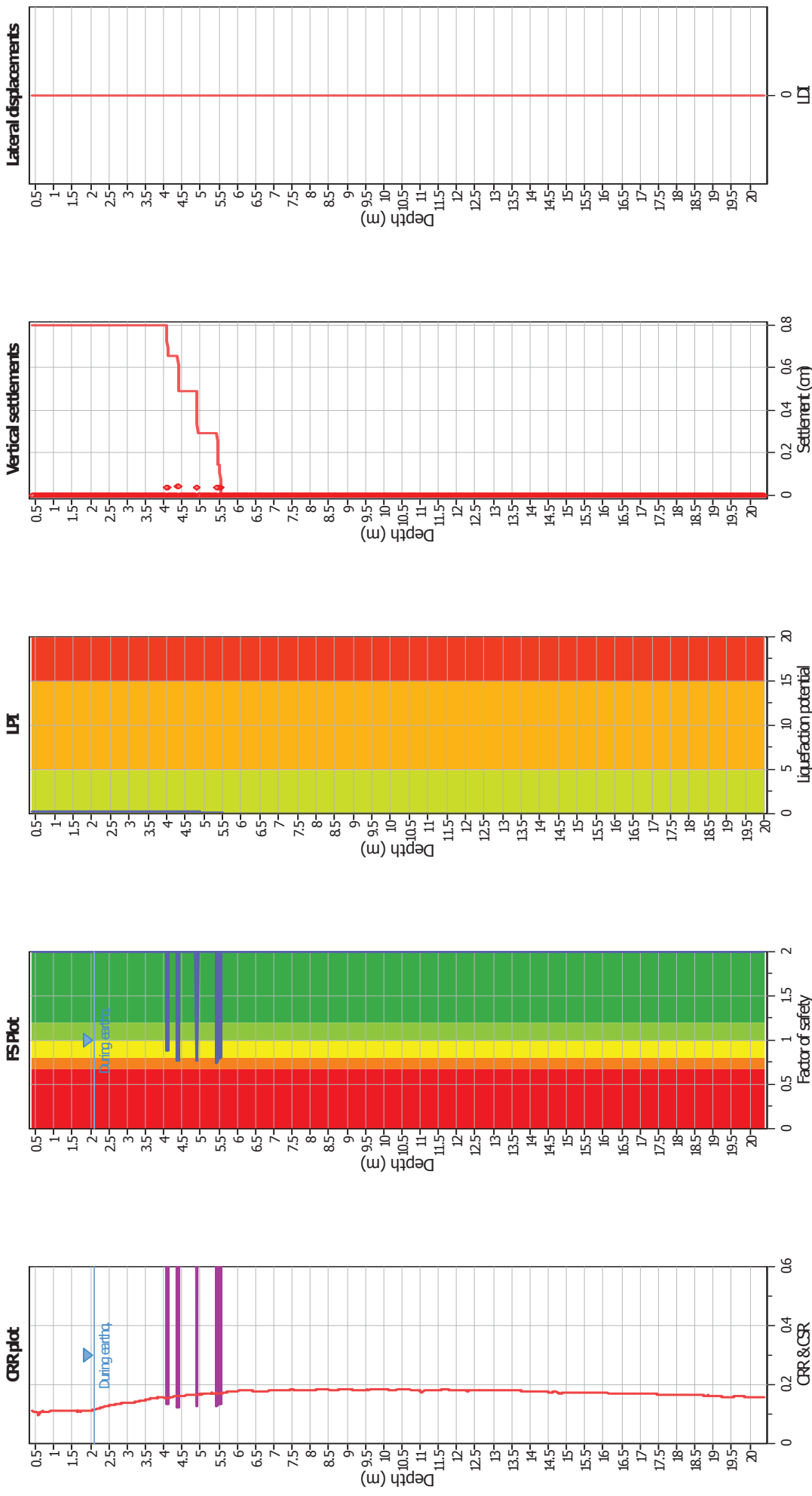
Liquefaction analysis overall plots (intermediate results)



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _u applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

Liquefaction analysis overall plots



Input parameters and analysis data

| | |
|--------------------------------|-------------------|
| Analysis method: | B&I (2014) |
| Fines correction method: | B&I (2014) |
| Points to test: | Based on Ic value |
| Earthquake magnitude M_w : | 6.14 |
| Peak ground acceleration: | 0.22 |
| Depth to water table (insitu): | 2.10 m |

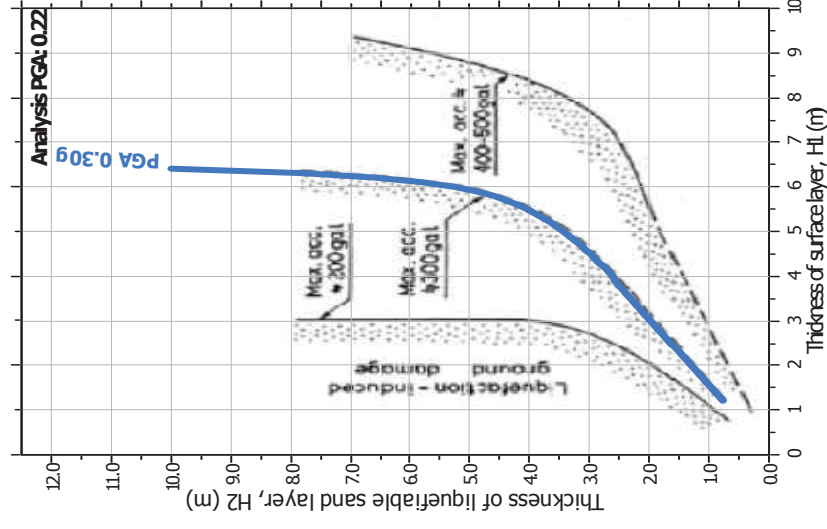
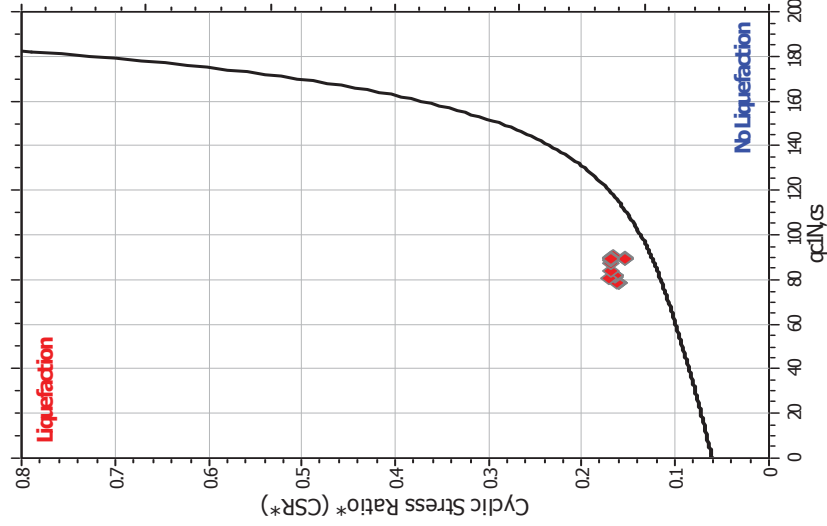
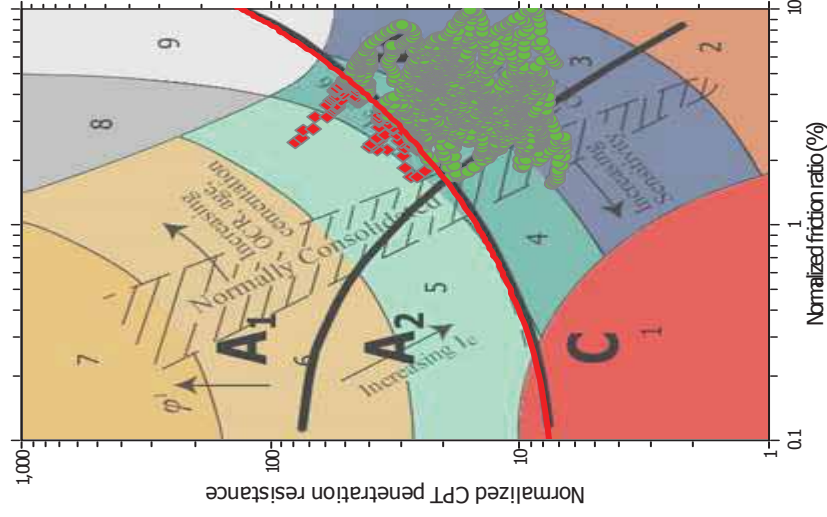
F.S. color scheme

| | |
|---|----------------|
| Almost certain it will liquefy | Very high risk |
| Very likely to liquefy | High risk |
| Liquefaction and no liq. are equally likely | Low risk |
| Unlike to liquefy | |
| Almost certain it will not liquefy | |

LPI color scheme

| |
|----------------|
| Very high risk |
| High risk |
| Low risk |

Liquefaction analysis summary plots



Input parameters and analysis data

| Analysis method: | B&I (2014) | Depth to GW ^T (erthq.): | Fill weight: |
|---------------------------------------|-------------------|------------------------------------|-----------------------------|
| Fines correction method: | B&I (2014) | Average results interval: | Transition detect. |
| Points to test: | Based on Ic value | Ic cut-off value: | K _s applied: |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Clay like behavior applied: |
| Peak ground acceleration: | 0.22 | Use fill: | Limit depth applied: |
| Depth to water table (insttu): | 2.10 m | Fill height: | Limit depth: |
| | | | N/A |
| | | | No |
| | | | Sands only |
| | | | Yes |
| | | | Yes |
| | | | N/A |

LIQUEFACTION ANALYSIS REPORT

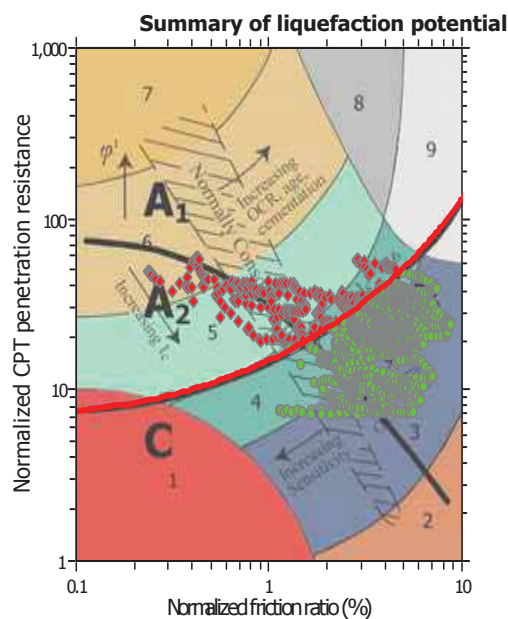
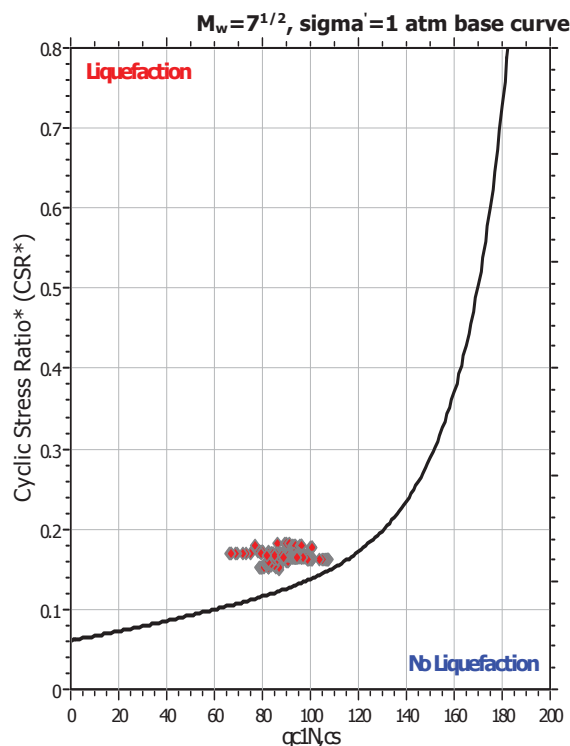
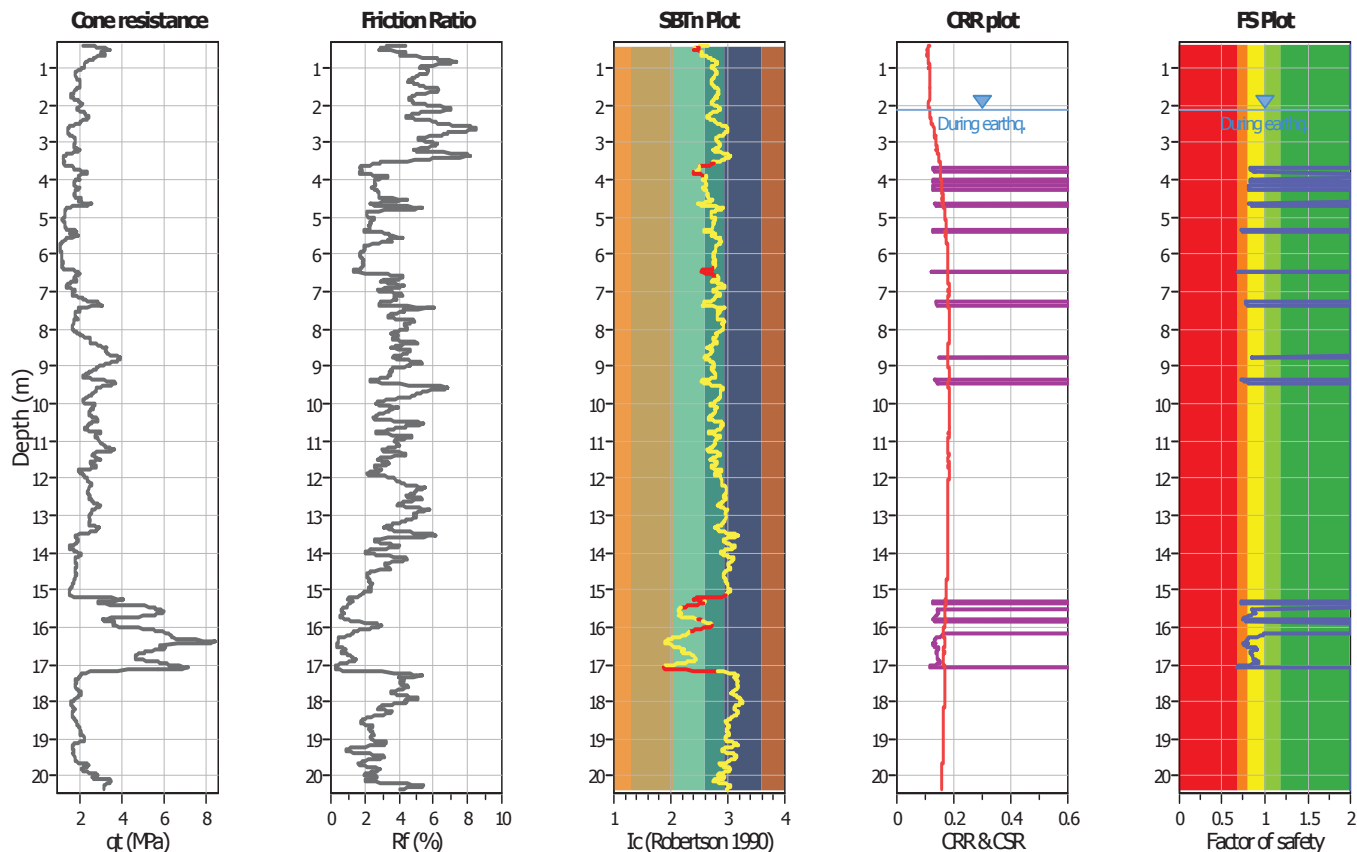
Project title : Studio del terreno di fondazione

Location : Fossoli, AIMAG

CPT file : CPTU5

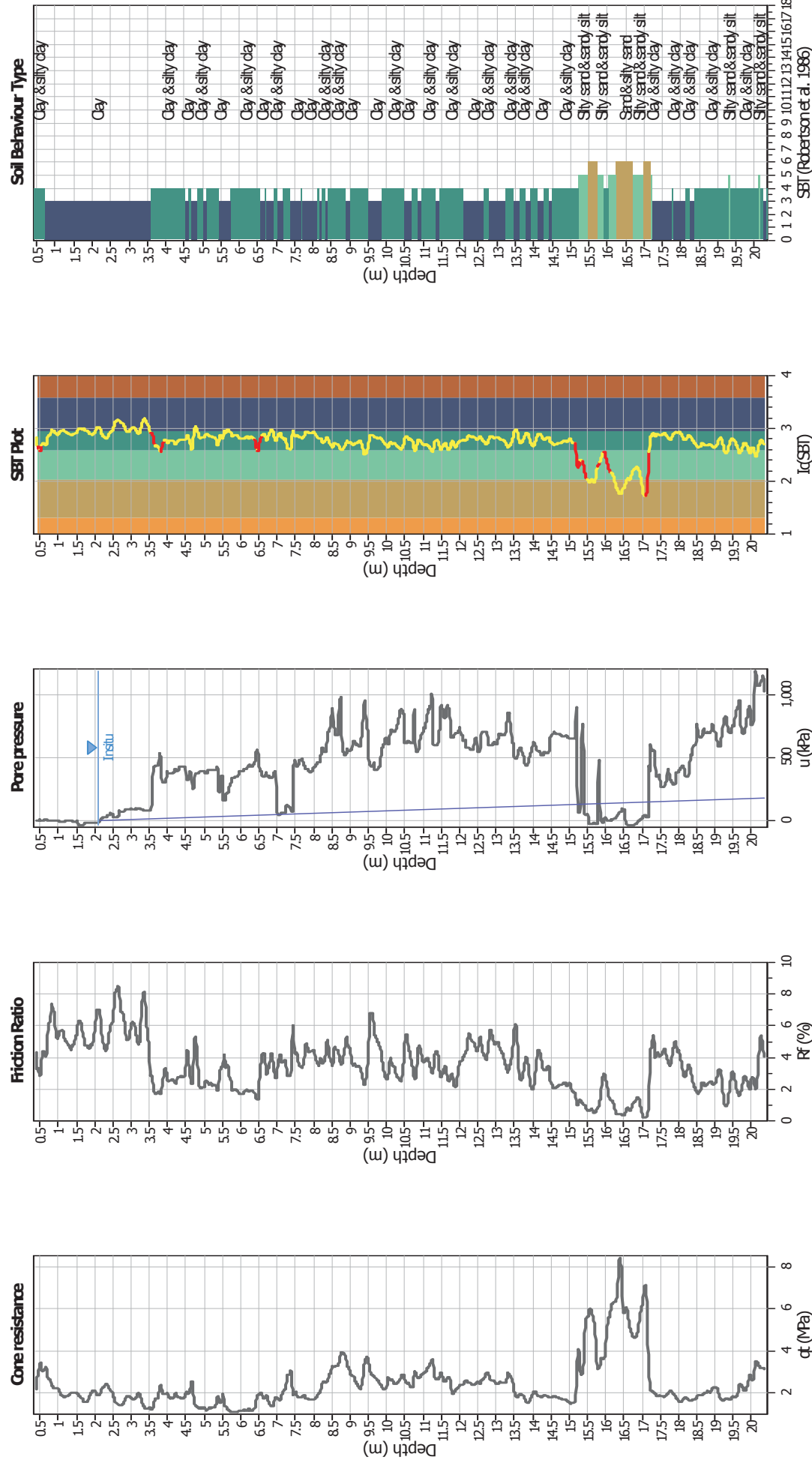
Input parameters and analysis data

| | | | | | | | |
|------------------------------|-------------------|---------------------------|--------------|-------------------------|-----|-----------------------------|------------|
| Analysis method: | B&I (2014) | G.W.T. (in-situ): | 2.10 m | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | B&I (2014) | G.W.T. (earthq.): | 2.10 m | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude M_w : | 6.14 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method |
| Peak ground acceleration: | 0.22 | Unit weight calculation: | Based on SBT | K_g applied: | Yes | | |



Zone A₁: Cyclic liquefaction likely depending on size and duration of cyclic loading
 Zone A₂: Cyclic liquefaction and strength loss likely depending on loading and ground geometry
 Zone B: Liquefaction and post-earthquake strength loss unlikely, check cyclic softening
 Zone C: Cyclic liquefaction and strength loss possible depending on soil plasticity, brittleness/sensitivity, strain to peak undrained strength and ground geometry

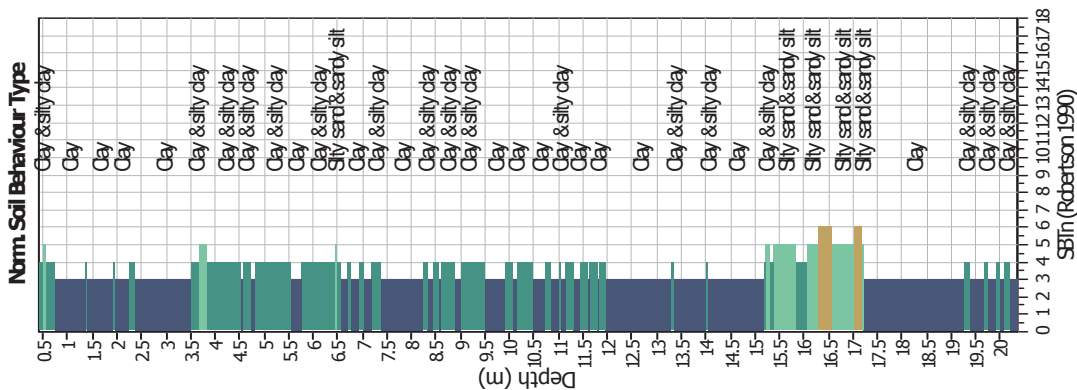
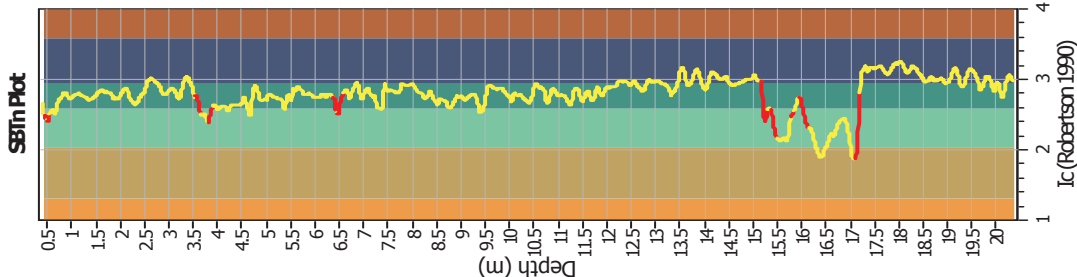
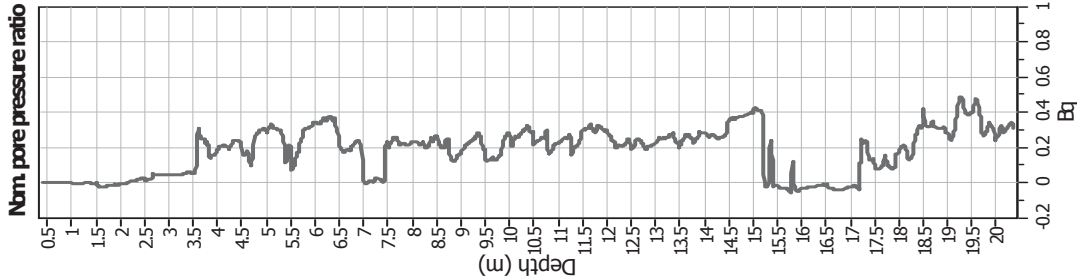
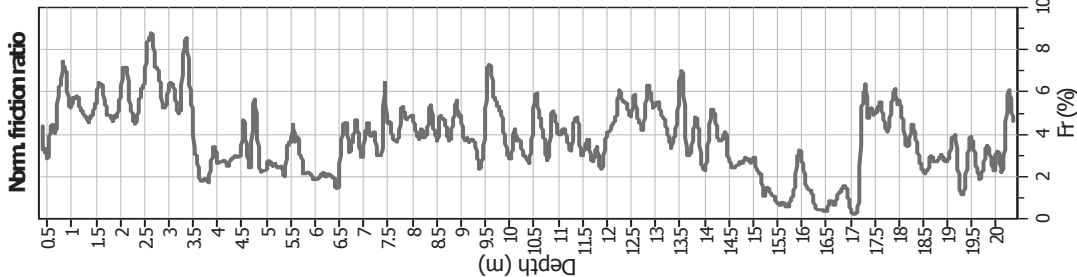
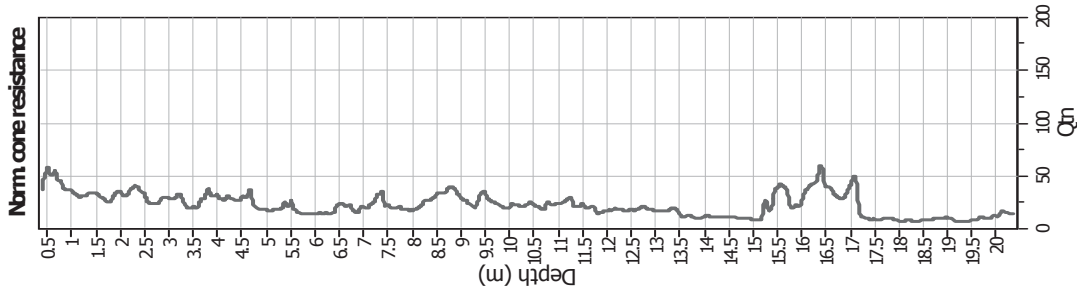
CPT basic interpretation plots



Input parameters and analysis data

| | B&I (2014) | Depth to GWT (erthq.): | Fill weight: |
|---------------------------------------|-------------------|---------------------------|-----------------------------|
| Analysis method: | | Average results interval: | Transition detect. |
| Fines correction method: | | Ic cut-off value: | K _s applied: |
| Points to test: | Based on Ic value | Unit weight calculation: | Clay like behavior applied: |
| Earthquake magnitude M _w : | 6.14 | Use fill: | Limit depth applied: |
| Peak ground acceleration: | 0.22 | Fill height: | Limit depth: |
| Depth to water table (insttu): | 2.10 m | | |
| | | | N/A |
| | | | No |
| | | | Sands only |
| | | | Yes |
| | | | Yes |

CPT basic interpretation plots (normalized)



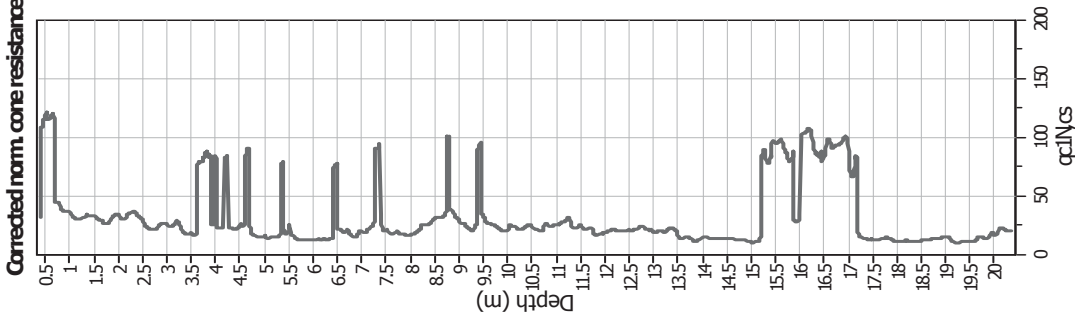
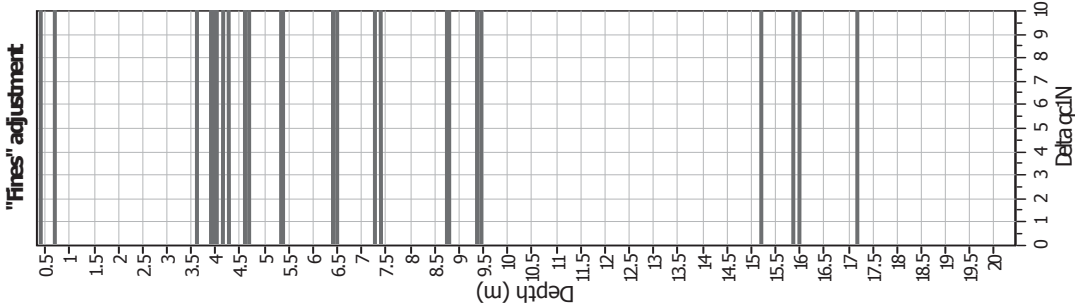
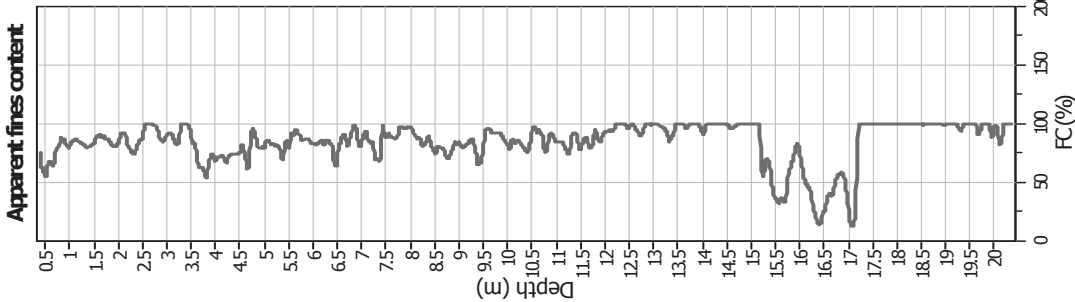
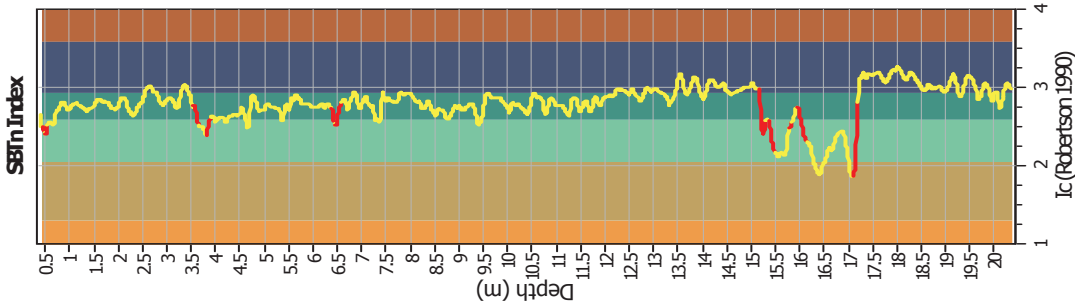
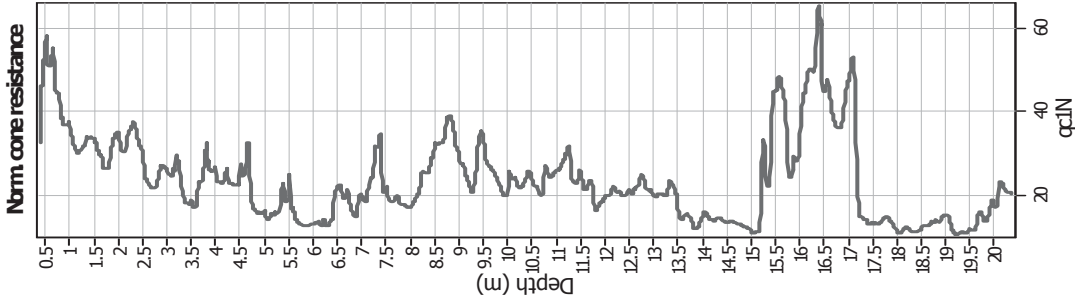
Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _u applied: | Sands only |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | No |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | N/A |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

SBTn legend

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

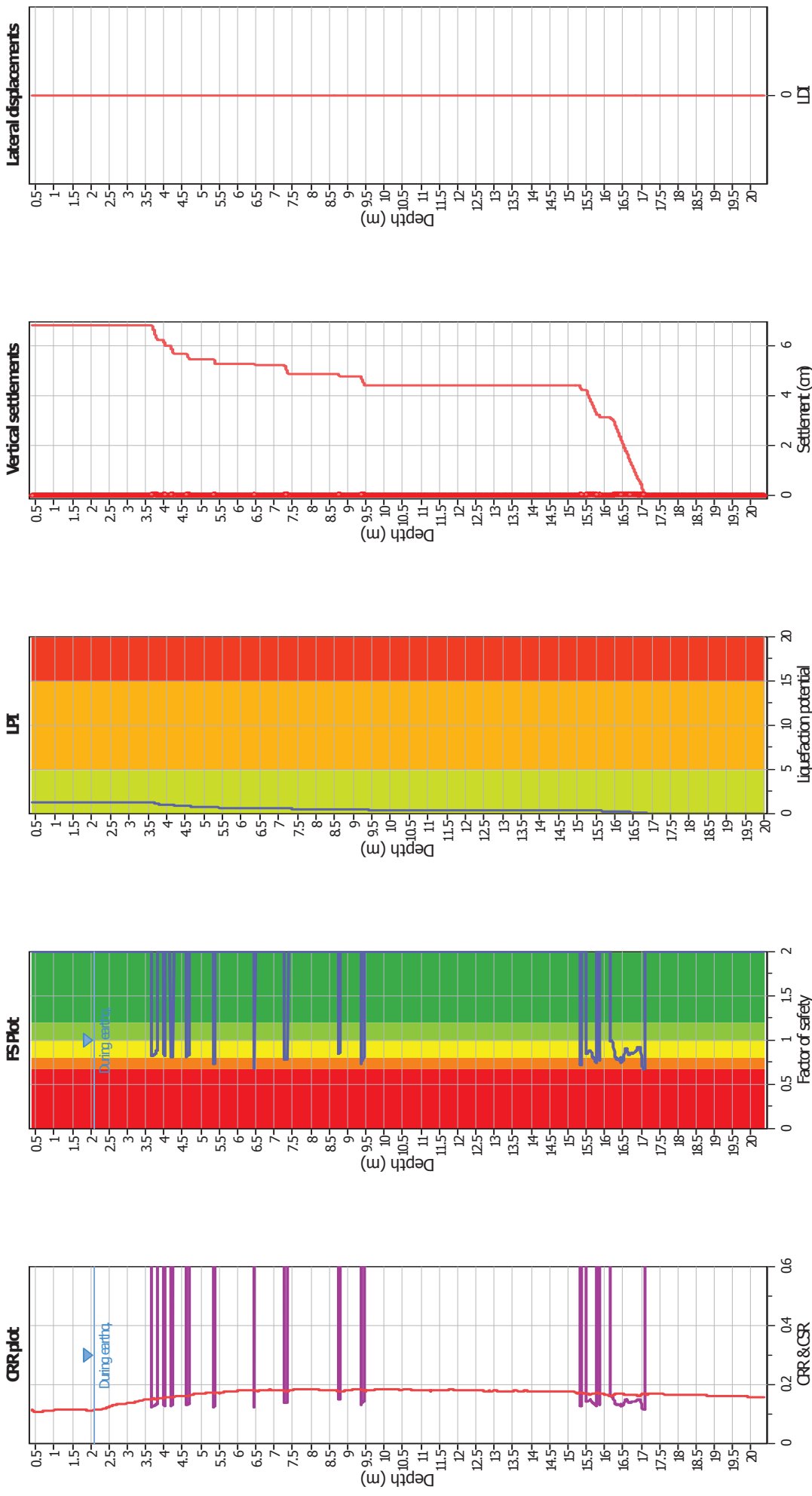
Liquefaction analysis overall plots (intermediate results)



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _u applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

Liquefaction analysis overall plots



Input parameters and analysis data

| | |
|--------------------------------|-------------------|
| Analysis method: | B&I (2014) |
| Fines correction method: | B&I (2014) |
| Points to test: | Based on Ic value |
| Earthquake magnitude M_w : | 6.14 |
| Peak ground acceleration: | 0.22 |
| Depth to water table (insitu): | 2.10 m |

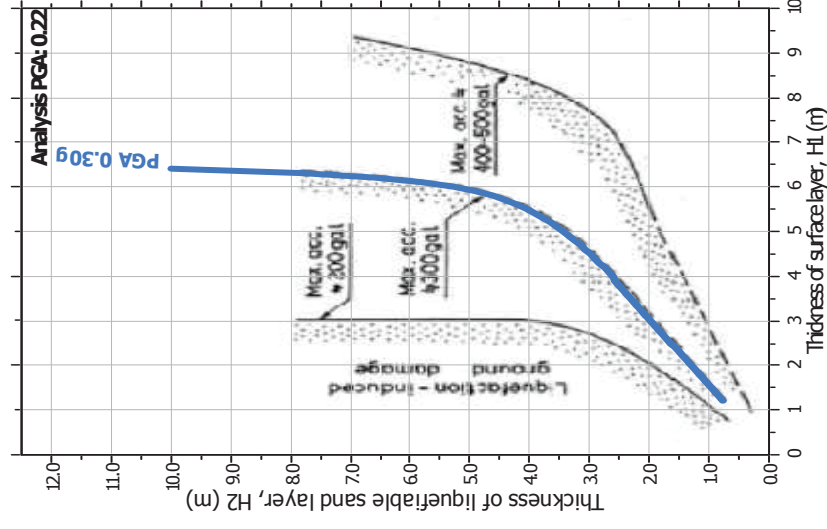
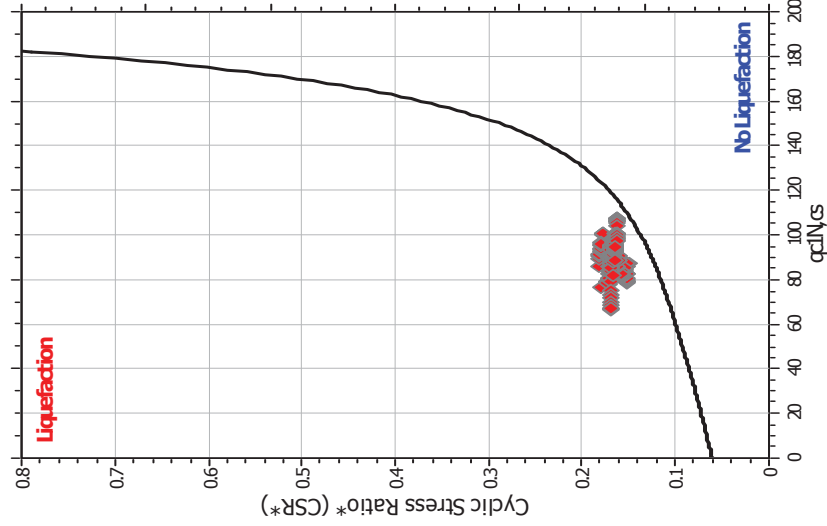
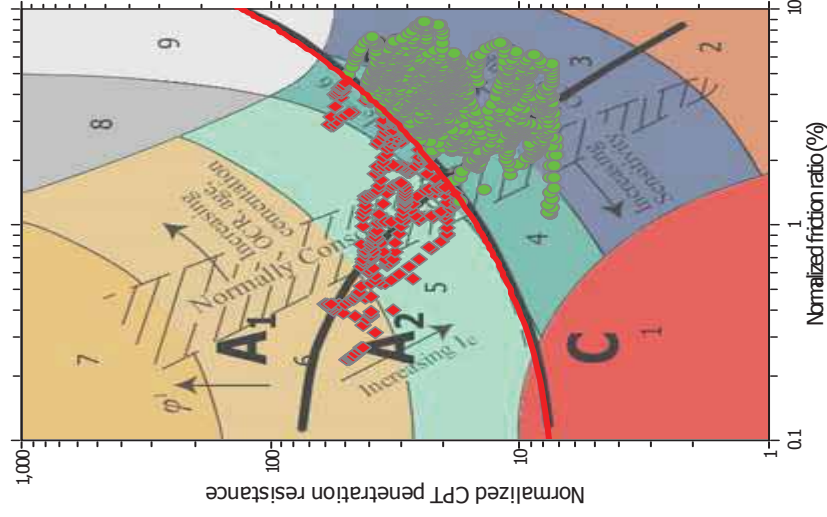
F.S. color scheme

| | |
|---|----------------|
| Almost certain it will liquefy | Very high risk |
| Very likely to liquefy | High risk |
| Liquefaction and no liq. are equally likely | Low risk |
| Unlike to liquefy | |
| Almost certain it will not liquefy | |

LPI color scheme

| |
|----------------|
| Very high risk |
| High risk |
| Low risk |

Liquefaction analysis summary plots



Input parameters and analysis data

| | B&I (2014) | Depth to GW ^T (erthq.): | Fill weight: | |
|---------------------------------------|-------------------|------------------------------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Average results interval: | Transition detect. | N/A |
| Fines correction method: | Based on Ic value | Ic cut-off value: | K _s applied: | Yes |
| Points to test: | 6-14 | Unit weight calculation: | Clay like behavior applied: | Sands only |
| Earthquake magnitude M _w : | 0.22 | Use fill: | Limit depth applied: | No |
| Peak ground acceleration: | 2.10 m | Fill height: | Limit depth: | N/A |
| Depth to water table (insttu): | | | | |

LIQUEFACTION ANALYSIS REPORT

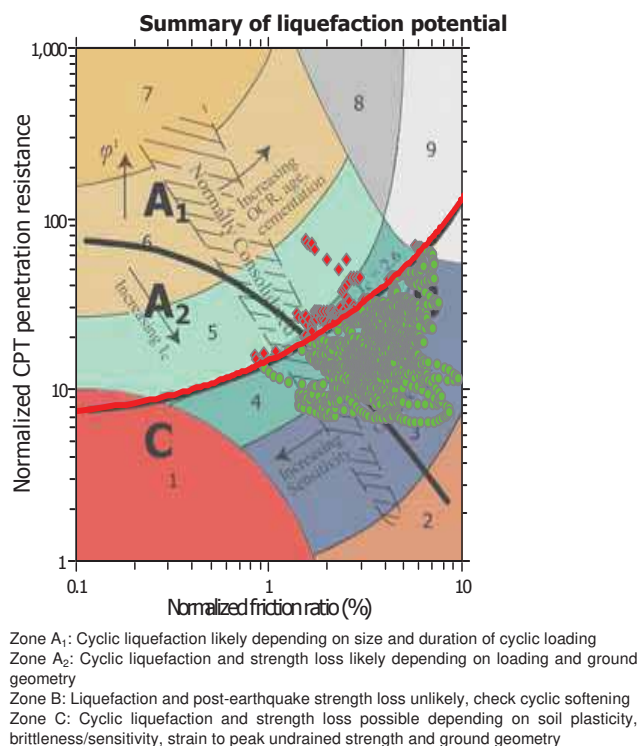
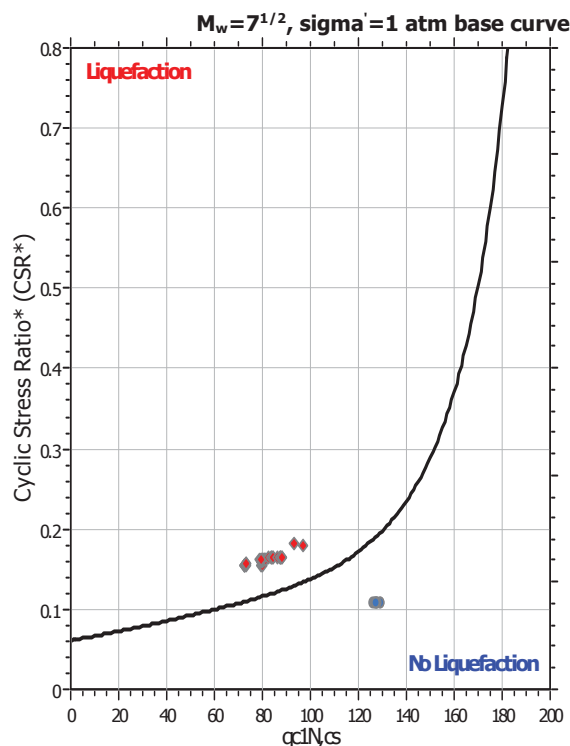
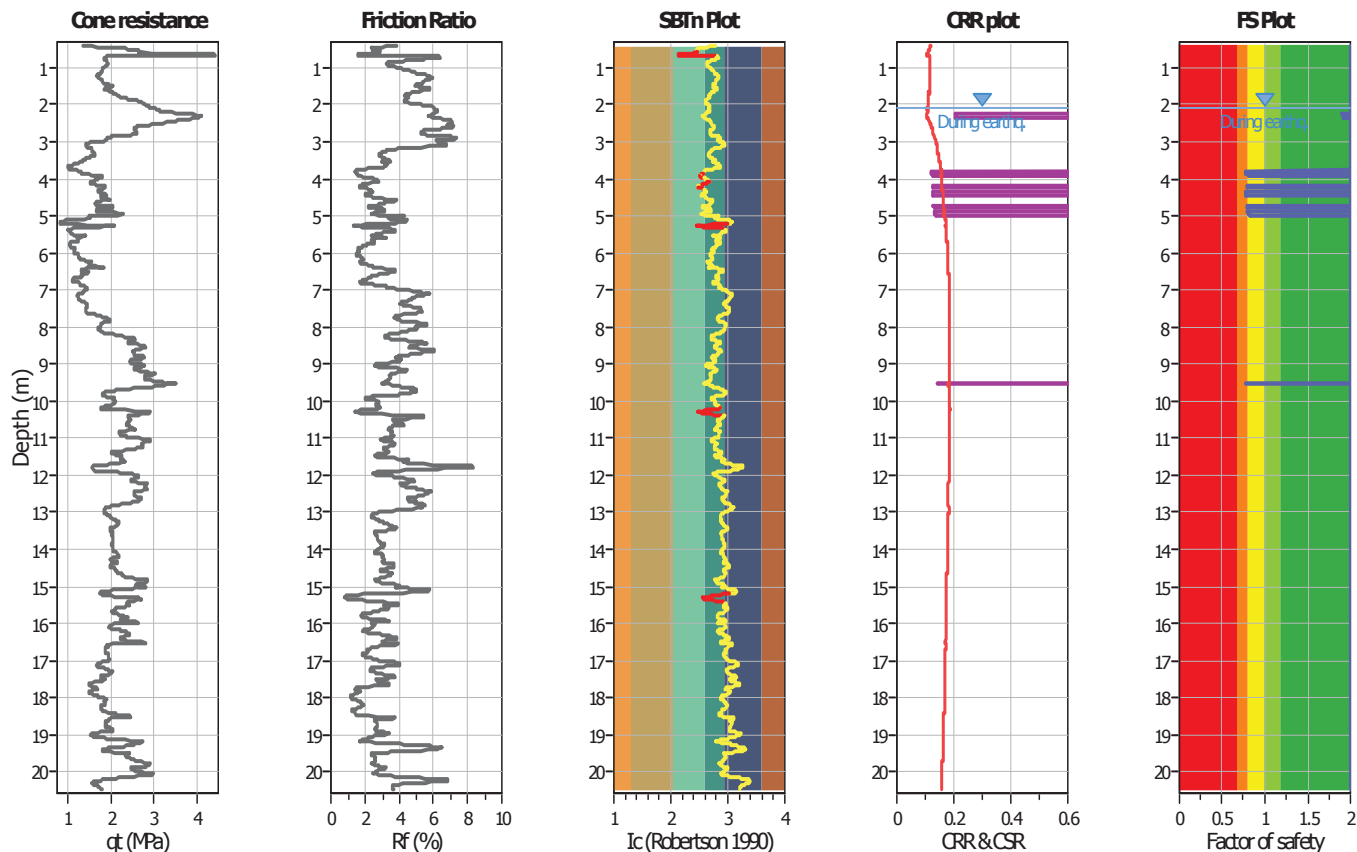
Project title : Studio del terreno di fondazione

Location : Fossoli, AIMAG

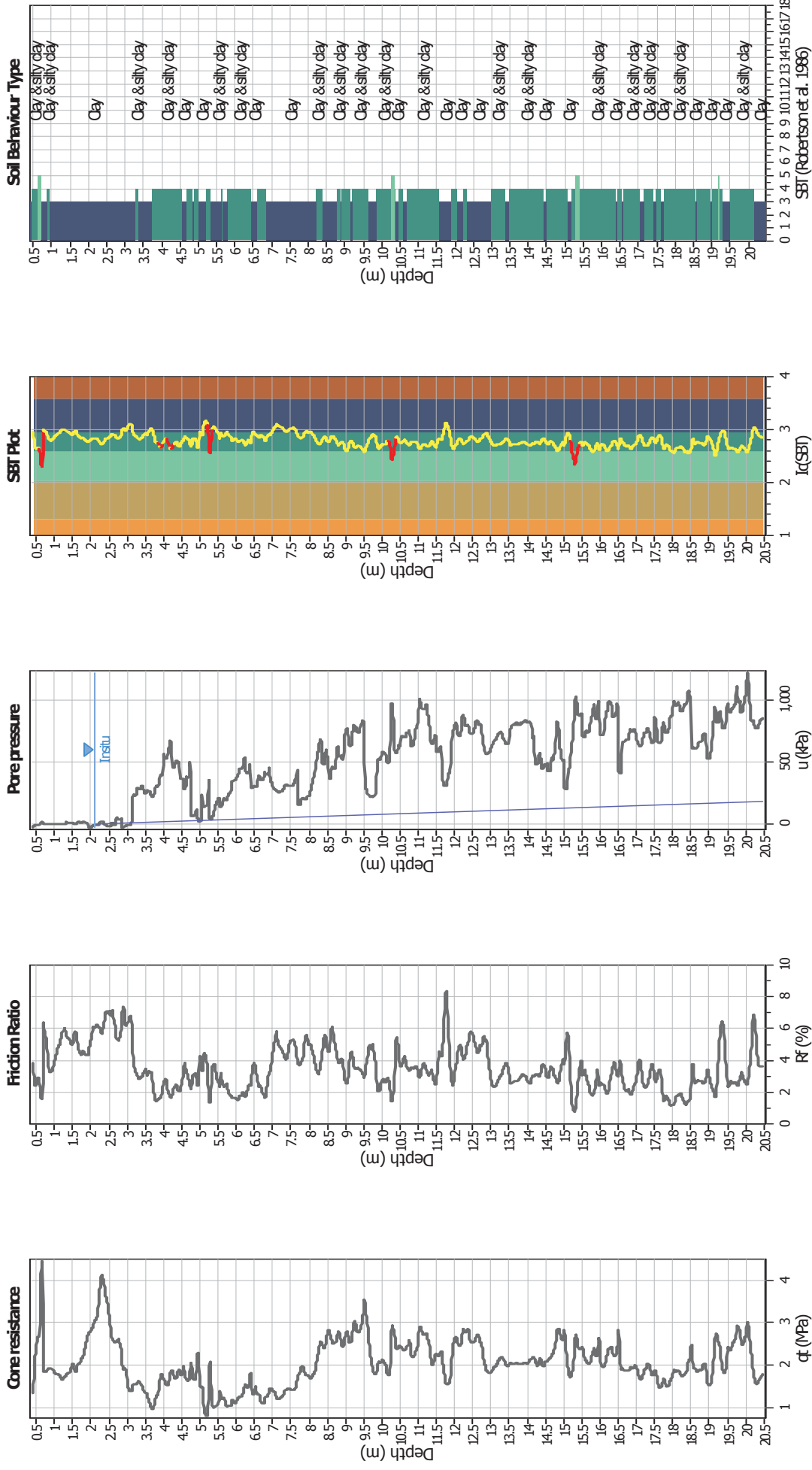
CPT file : CPTU6

Input parameters and analysis data

| | | | | | | | |
|------------------------------|-------------------|---------------------------|--------------|-------------------------|-----|-----------------------------|------------|
| Analysis method: | B&I (2014) | G.W.T. (in-situ): | 2.10 m | Use fill: | No | Clay like behavior applied: | Sands only |
| Fines correction method: | B&I (2014) | G.W.T. (earthq.): | 2.10 m | Fill height: | N/A | Limit depth applied: | No |
| Points to test: | Based on Ic value | Average results interval: | 3 | Fill weight: | N/A | Limit depth: | N/A |
| Earthquake magnitude M_w : | 6.14 | Ic cut-off value: | 2.60 | Trans. detect. applied: | Yes | MSF method: | Method |
| Peak ground acceleration: | 0.22 | Unit weight calculation: | Based on SBT | K_g applied: | Yes | | |



CPT basic interpretation plots



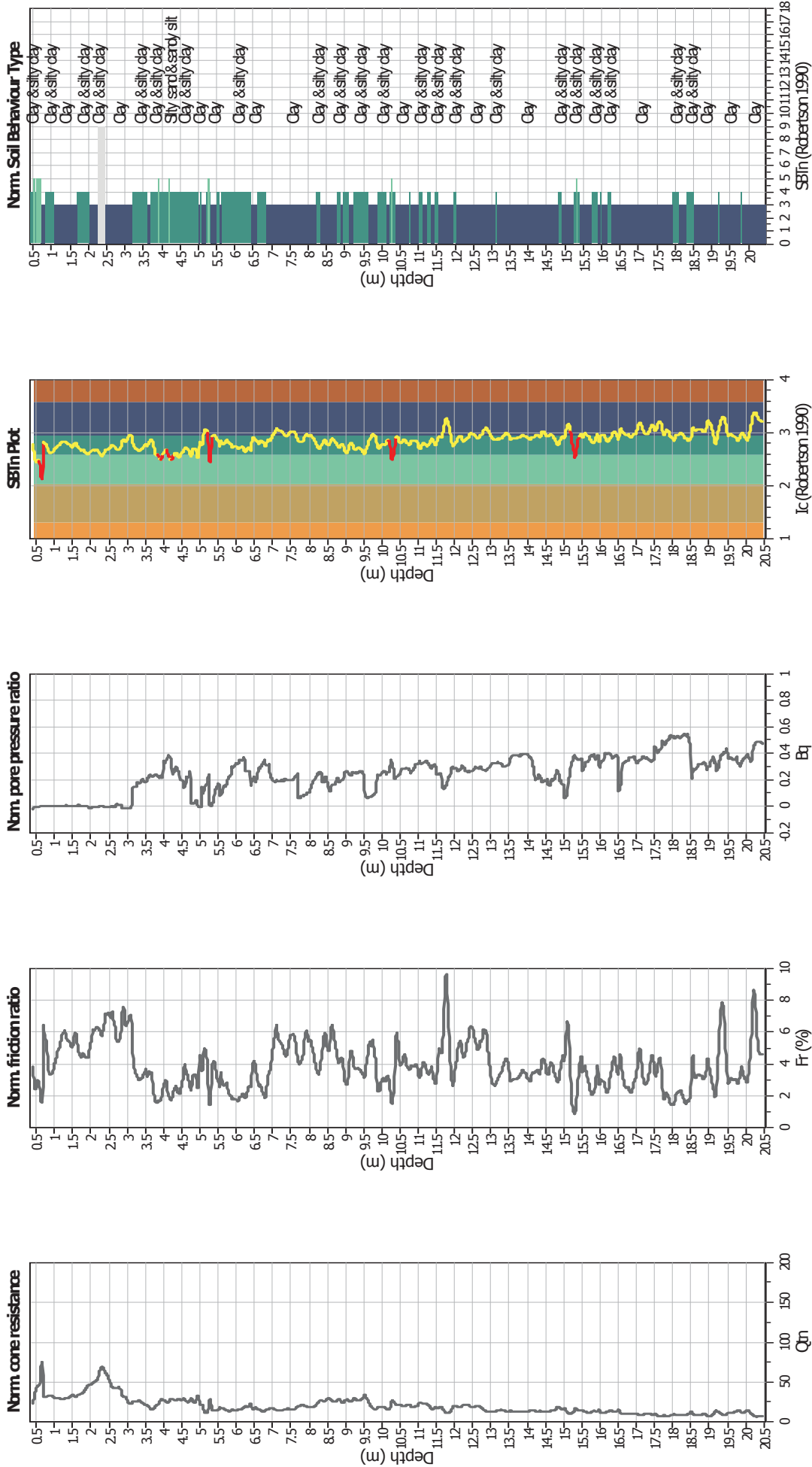
Input parameters and analysis data

| | | | | | |
|--------------------------------|----------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on I_c value | I_c cut-off value: | 2.60 | K_p applied: | Yes |
| Earthquake magnitude M_w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

SBT legend

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

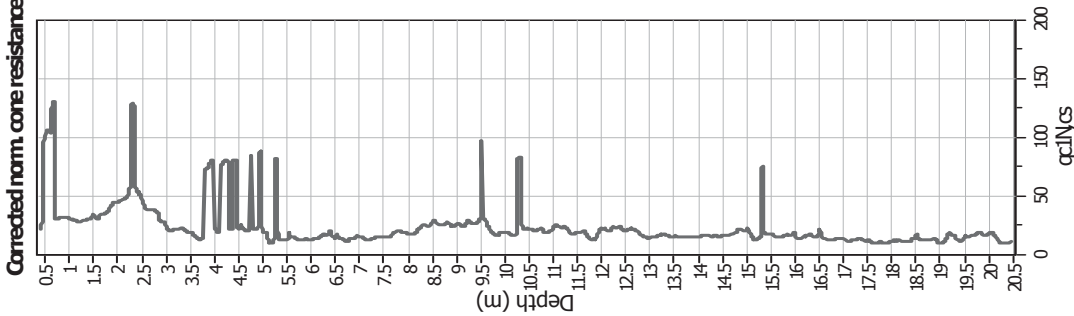
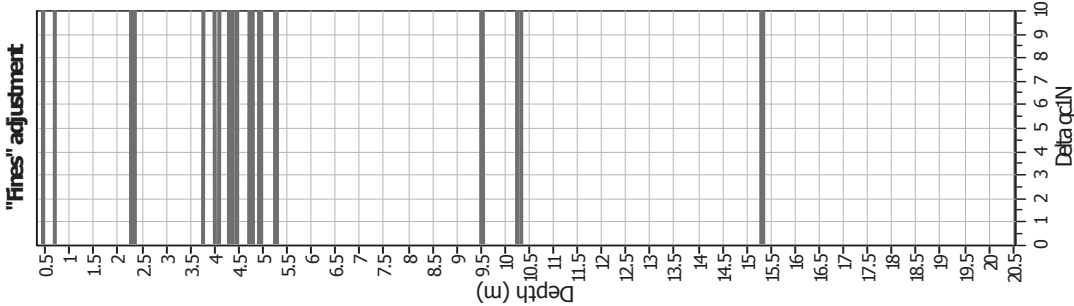
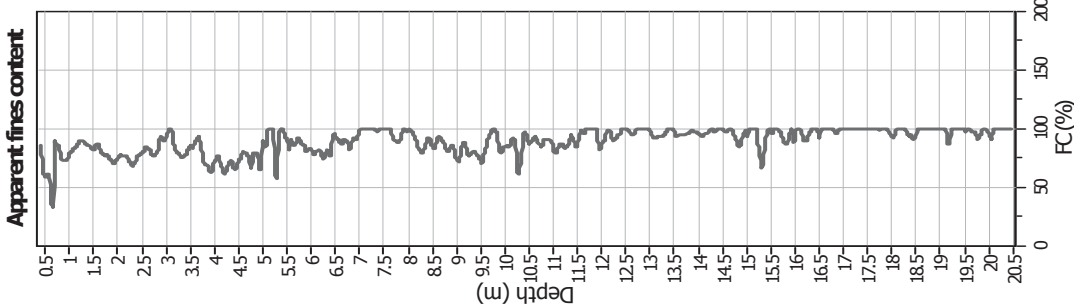
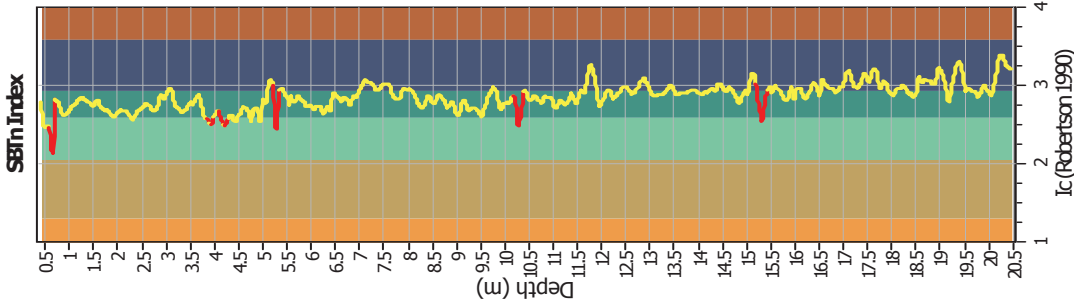
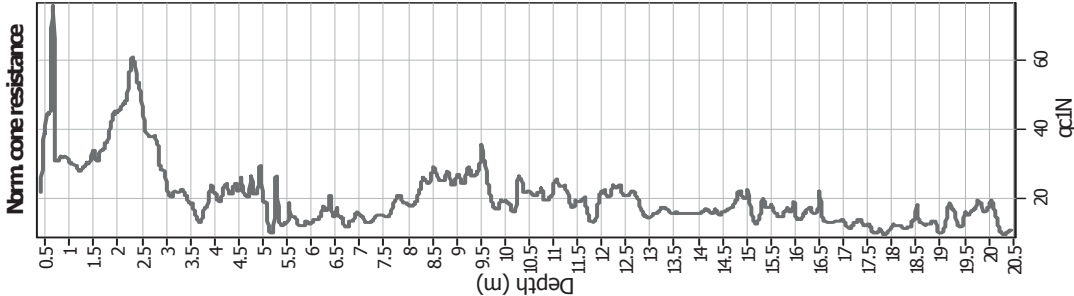
CPT basic interpretation plots (normalized)



Input parameters and analysis data

| | | | | | |
|--------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K_v applied: | Yes |
| Earthquake magnitude M_w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

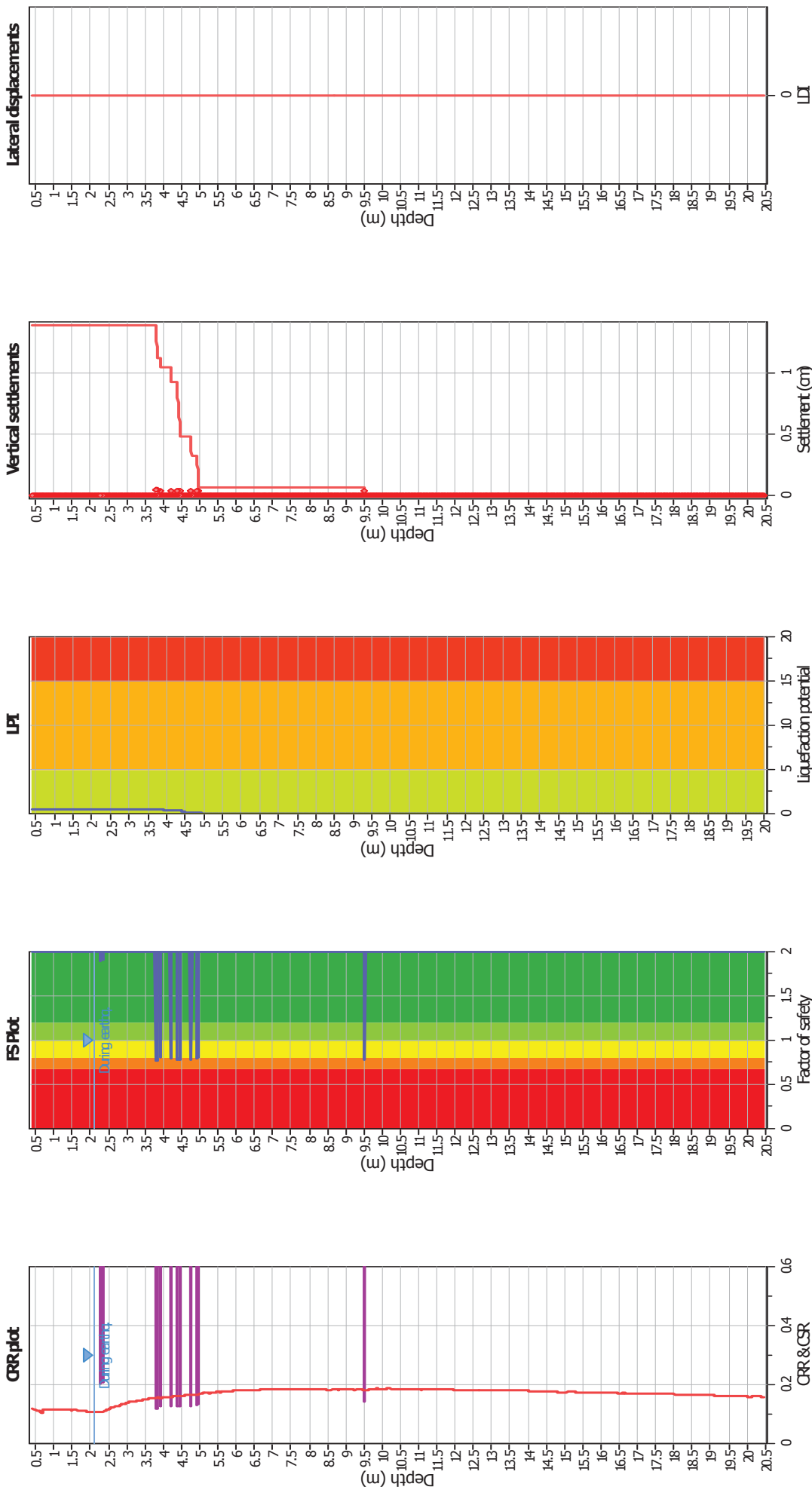
Liquefaction analysis overall plots (intermediate results)



Input parameters and analysis data

| | | | | | |
|---------------------------------------|-------------------|---------------------------|--------------|-----------------------------|------------|
| Analysis method: | B&I (2014) | Depth to GWT (erthq.): | 2.10 m | Fill weight: | N/A |
| Fines correction method: | B&I (2014) | Average results interval: | 3 | Transition detect. applied: | Yes |
| Points to test: | Based on Ic value | Ic cut-off value: | 2.60 | K _{cs} applied: | Yes |
| Earthquake magnitude M _w : | 6.14 | Unit weight calculation: | Based on SBT | Clay like behavior applied: | Sands only |
| Peak ground acceleration: | 0.22 | Use fill: | No | Limit depth applied: | No |
| Depth to water table (insitu): | 2.10 m | Fill height: | N/A | Limit depth: | N/A |

Liquefaction analysis overall plots



Input parameters and analysis data

| | |
|--------------------------------|-------------------|
| Analysis method: | B&I (2014) |
| Fines correction method: | B&I (2014) |
| Points to test: | Based on Ic value |
| Earthquake magnitude M_w : | 6.14 |
| Peak ground acceleration: | 0.22 |
| Depth to water table (insitu): | 2.10 m |

F.S. color scheme

| | | | | |
|--------------------------------|------------------------|---|-------------------|------------------------------------|
| Almost certain it will liquefy | Very likely to liquefy | Liquefaction and no liq. are equally likely | Unlike to liquefy | Almost certain it will not liquefy |
| Red | Orange | Yellow | Green | Dark Green |

LPI color scheme

| | | |
|----------------|-----------|----------|
| Very high risk | High risk | Low risk |
| Red | Orange | Green |

