Bayesian strain-rate correction for marine sediments characterization

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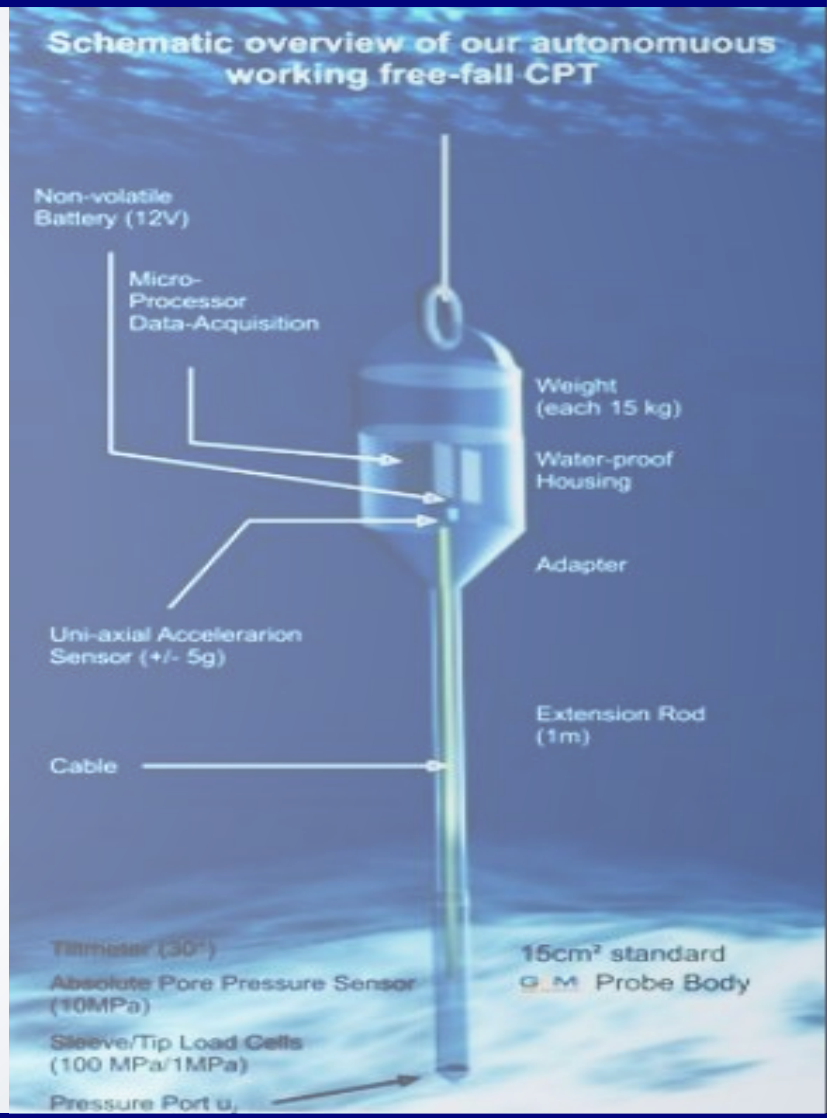

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Dynamic Cone Penetration Test

- Introduction

- Main uncertainty in Dynamic data process: Strain-Rate effect

- How to improve conversion accuracy from Dynamic to Static measurements?
  (Further predict of geotechnical design parameters (e.g. Cu, friction angle)

Dynamic Cone Penetration Test (SW-CPTu)

Shallow water Dynamic CPTu (500m water depth)

Application:
- Marine geosciences (e.g. slope stability research);
- Engineering practice (e.g. exploration of cable tracks).

Main advantages vs Static CPTu:
- Relative light-weight;
- Fast test execution;
- Less sensitive to bad weather conditions (Stegmann 2006).

Main drawback:
- Penetration velocity >> static test (constant velocity)
- Data process requires rate effect quantification.

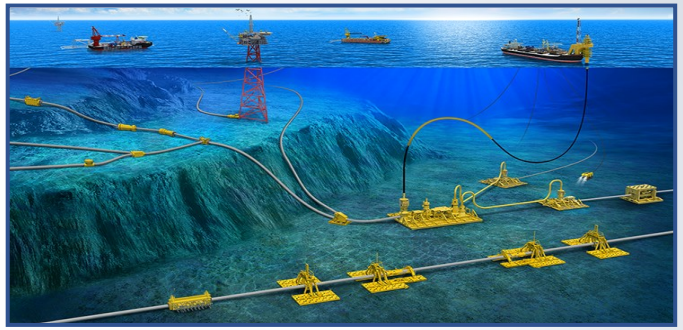


Figure 1. Submarine application of Dynamic CPTu

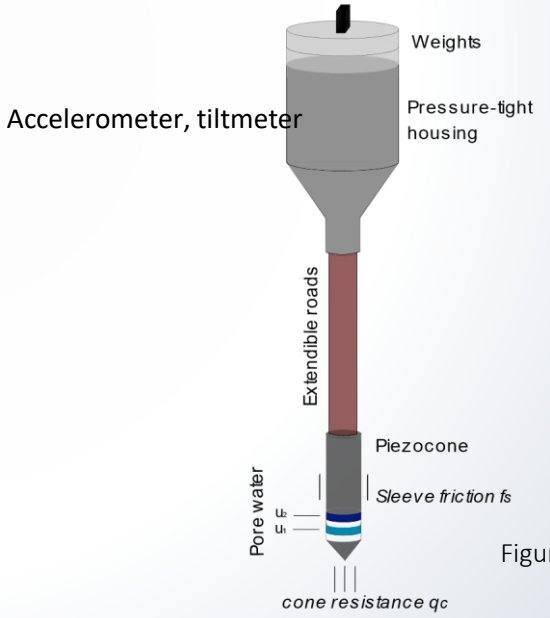


Figure 2. Skecth of Dynamic CPTu equipment

Introduction: Strain-Rate effect

Key Point: Soil properties depend on the rate at which soils are deformed (strain rate).

Rate effect in fine grained soils:

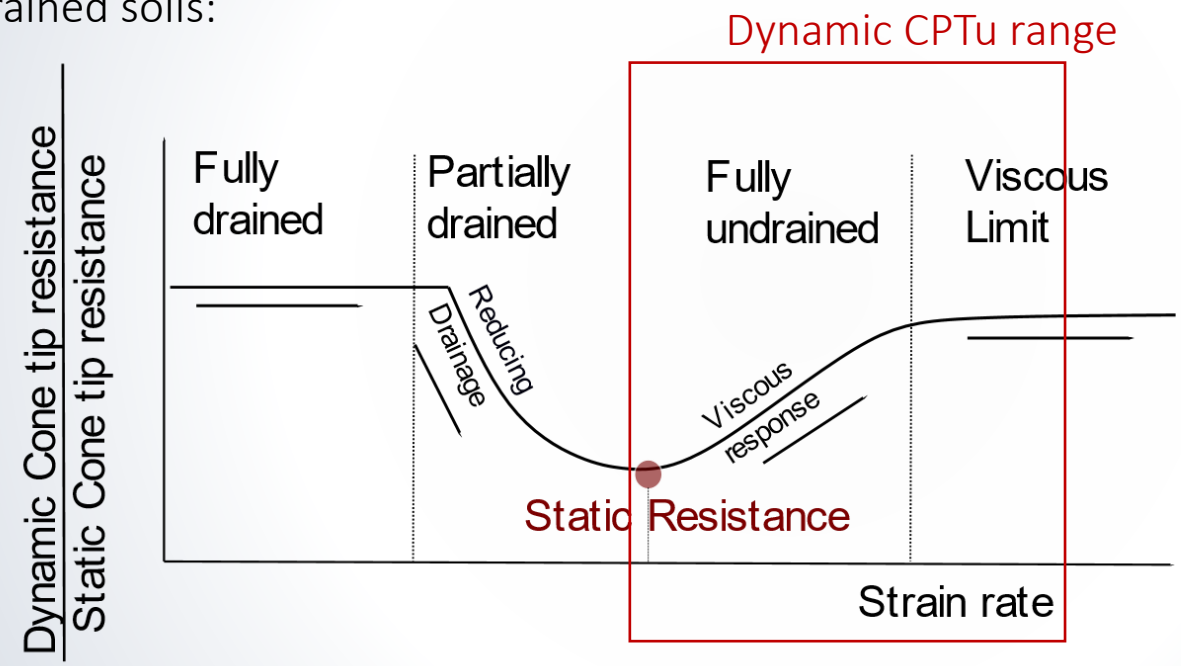


Figure 3. Rate effect variation at varying strain level (Quinn and Brown, 2011, Lehane et al., 2009)

Introduction: Strain-Rate effect

Example:
Homogeneous clay samples

1st issue:
Strain-rate effect q_t
≠
Strain-rate effect *fs*

2nd issue:
Strain-rate (Impact Velocity, depth, Soil Type)

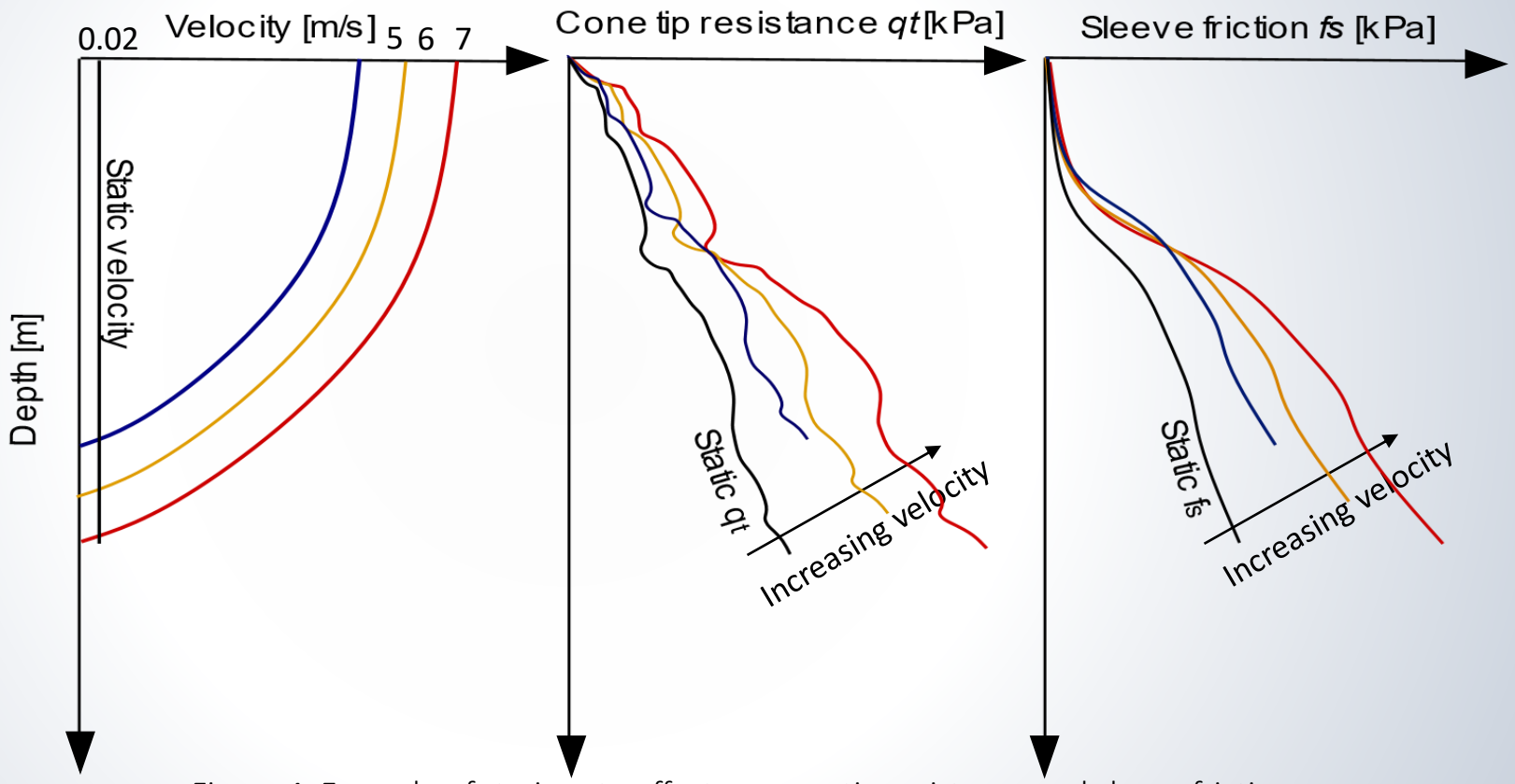


Figure 4. Example of strain-rate effect on cone tip resistance and sleeve friction

Each CPTu measurements must be converted to static ones

Introduction: Strain-Rate Coefficient

SRF = Strain-Rate Factor

$$\mathrm{SRF} = \left(\frac{v_{dyn}}{v_{stat}}\right)^{\beta}$$

v_{dyn} = penetration velocity of SW- CPTu;
v_{stat} = penetration velocity of static CPTu;

Known parameters

$\boldsymbol{\beta}$= strain-rate coefficient

Simplistic model:

$$\text{Converted } q_{t\,static} = q_{t\,dyn} / \mathrm{SRF}$$

Introduction: Strain-Rate Coefficient

General data acquisition at a site: Dynamic CPTU + Gravity cores

General approach: $\boldsymbol{\beta}$ estimated from Literature: average value from experimental studies

Literature: empirical estimation of $\boldsymbol{\beta}$:
(Steiner et al., 2012, Chow et al. 2017, Lehane et al. 2009)

- Homogenous soil tested (e.g. clay, active clays)
- Different impact velocity
- No empirical correlations available

Possible misleading conversion of in situ CPTu

How to improve $\boldsymbol{\beta}$ prediction?

Minimizing: $q_{t-stat} - q_{t\,dyn} / \left(\frac{v_{dyn}}{v_{stat}}\right)^{\beta} = 0$

$$\mu_{(q_{t-stat})} - \mu\left(q_{t\,dyn} / \left(\frac{v_{dyn}}{v_{stat}}\right)^{\beta}\right) = 0$$

Mean value Mean value

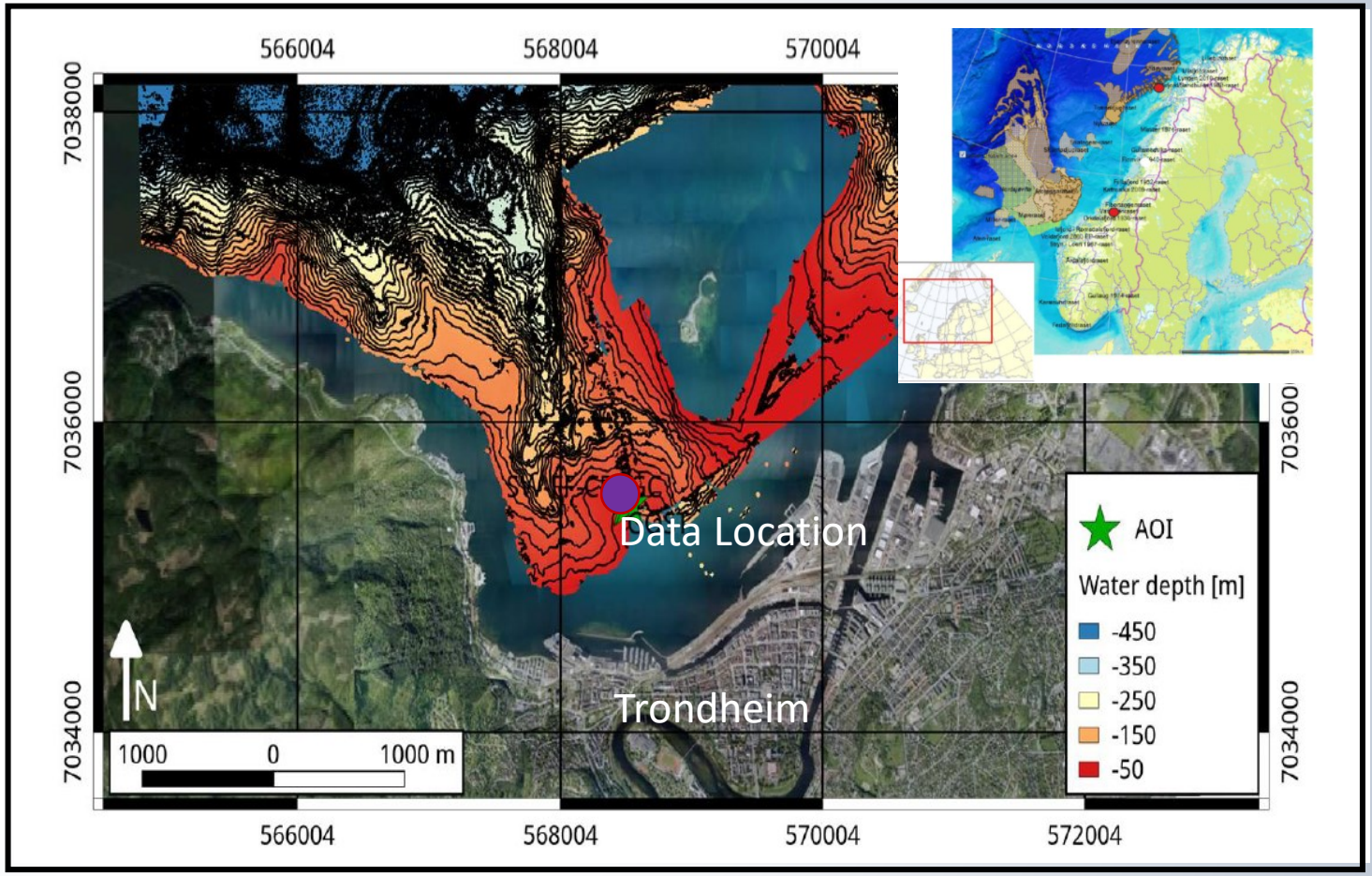
$f\,(\mu_{(q_{t-stat})}, \beta) = 0$

Unknown: $\mu_{(q_{t-stat})}, \beta$

Study area:

Location: Trondheim, Norway.

Recent studies: Roskoden 2015-Phd Thesis, L'Heureux, J. et al., 2010).

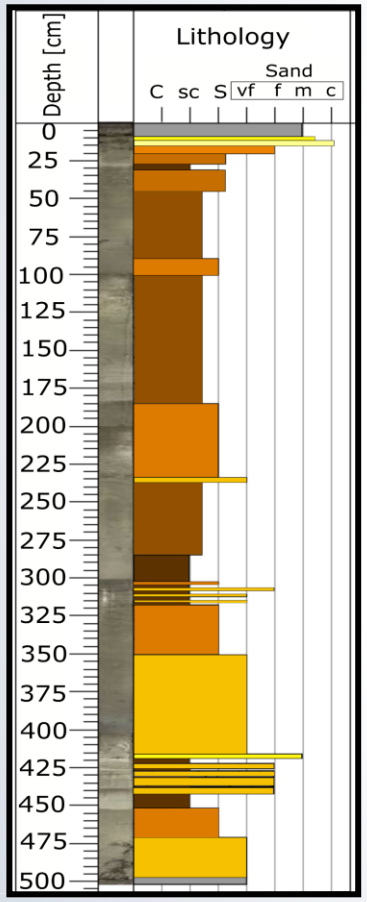


Roskoden (2015),PhD Thesis.

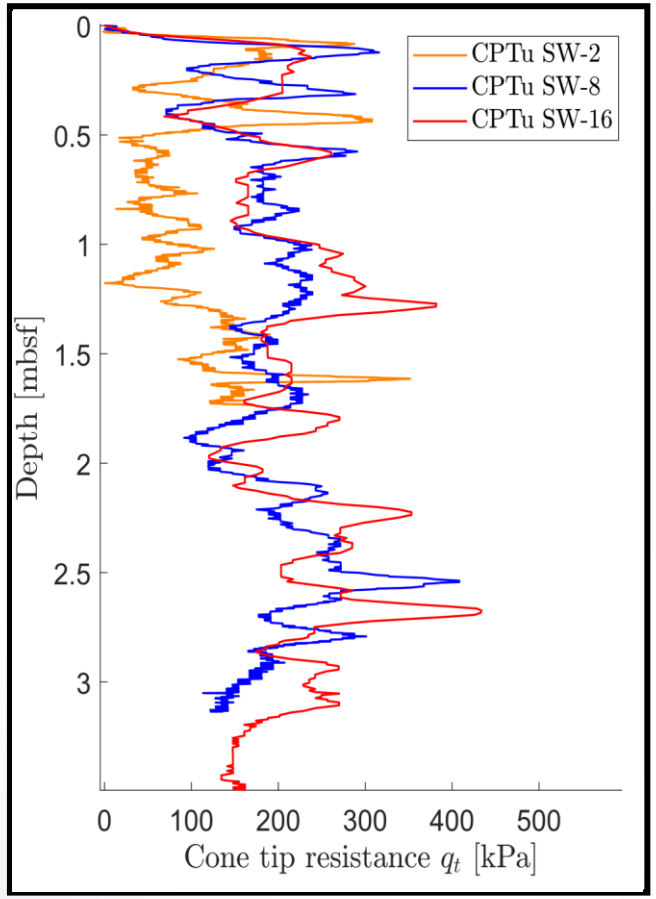
Data acquired:

- Gravity cores
- 16 Dynamic CPTu
- Lab. Data (Soil unit weight)

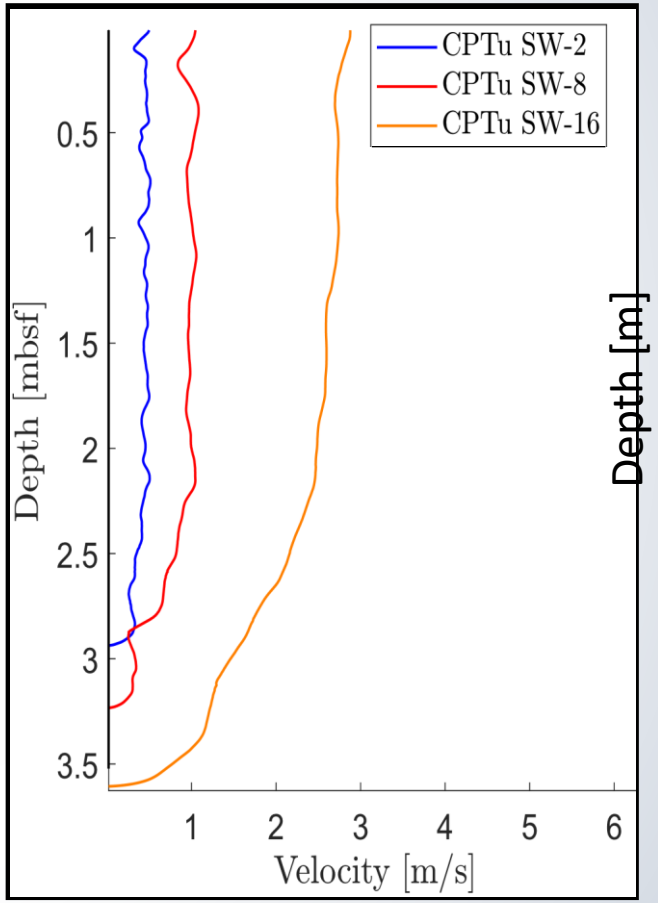
Gravity cores



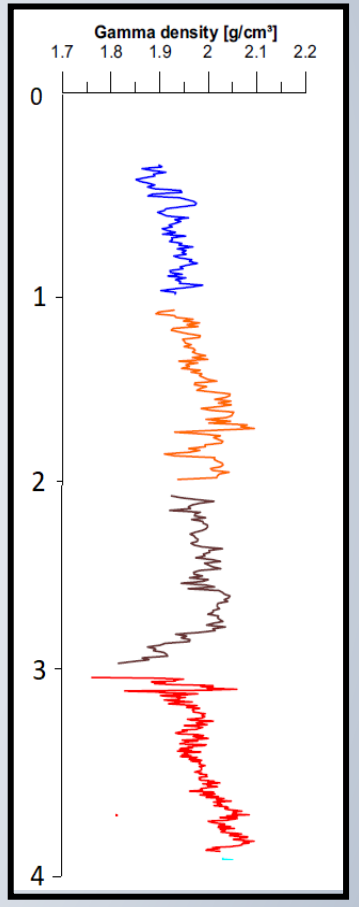
Dynamic CPTu



Penetration velocity [m/s]



Lab. Data



Unknown: $\mu_{(q_{t-stat})}$, β

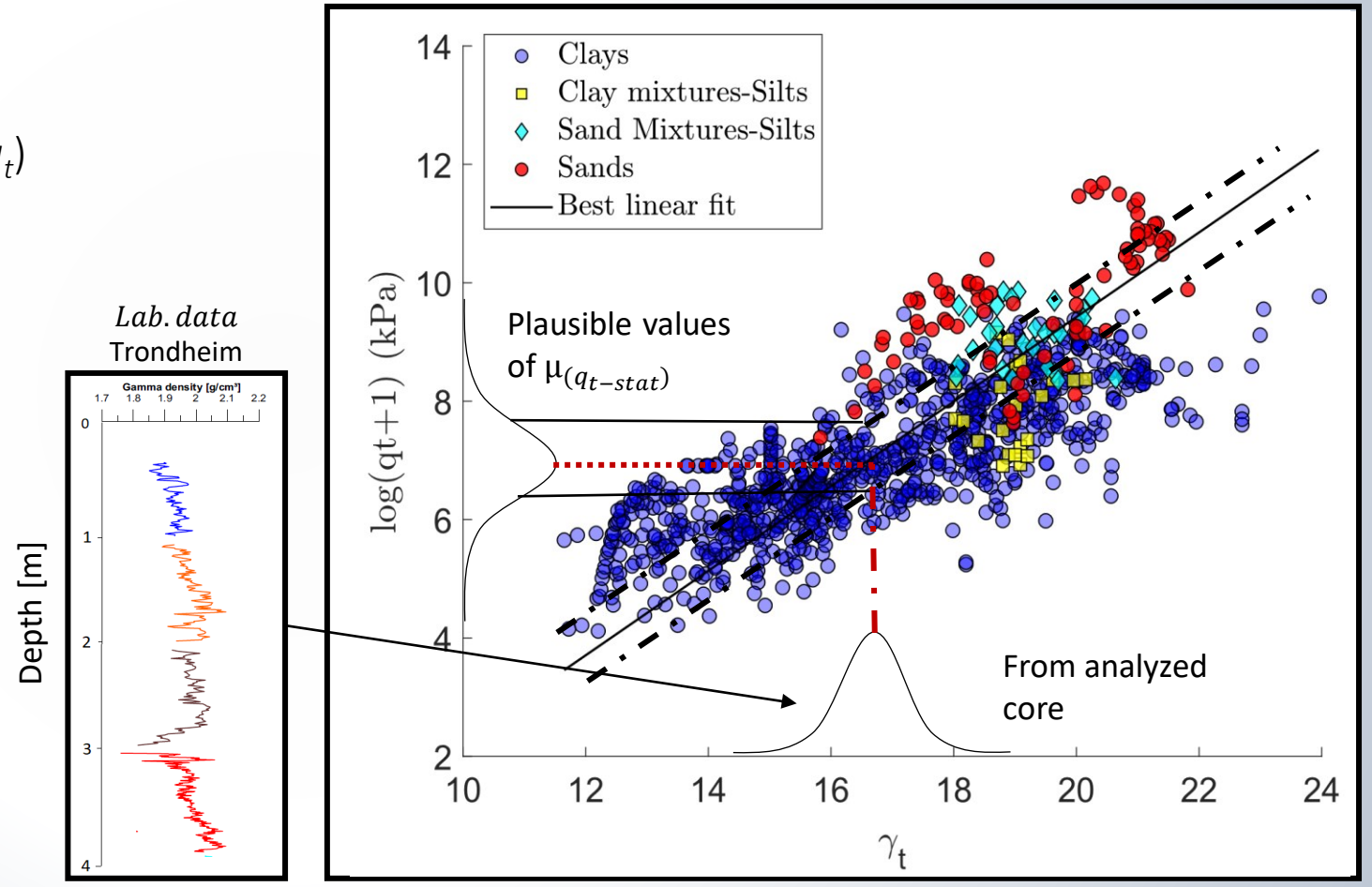
$\mu_{(q_{t-stat})}$: Empirical correlations
Soil unit weight- static CPTu parameters (e.g. q_t)

Regression introduce uncertainty $\mu_{(q_{t-stat})}$

↓

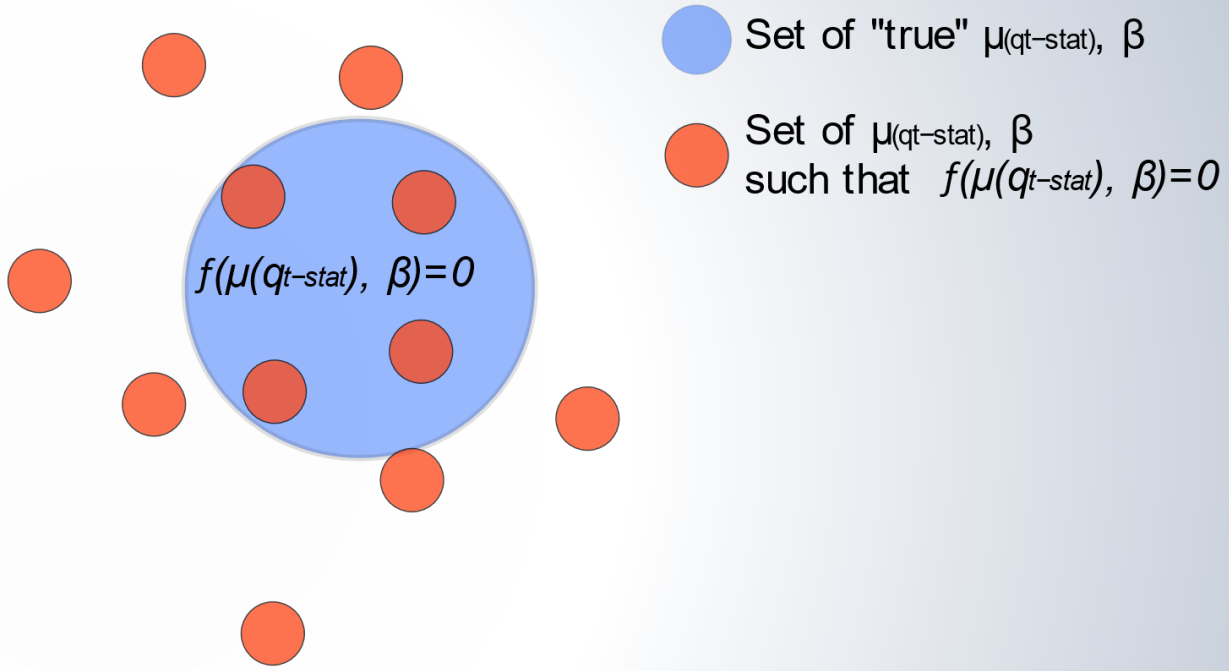
$f\ (\mu_{(q_{t-stat})}, \beta) = 0$

Probabilistic approach



$$\mu_{(q_{t-stat})} - \mu\left(q_{t\,dyn} \,/\, \left(\frac{v_{dyn}}{v_{stat}}\right)^{\beta}\right) = 0$$

~~Least square method: poorly condition~~
(Observations & exponential coefficient -unknown)

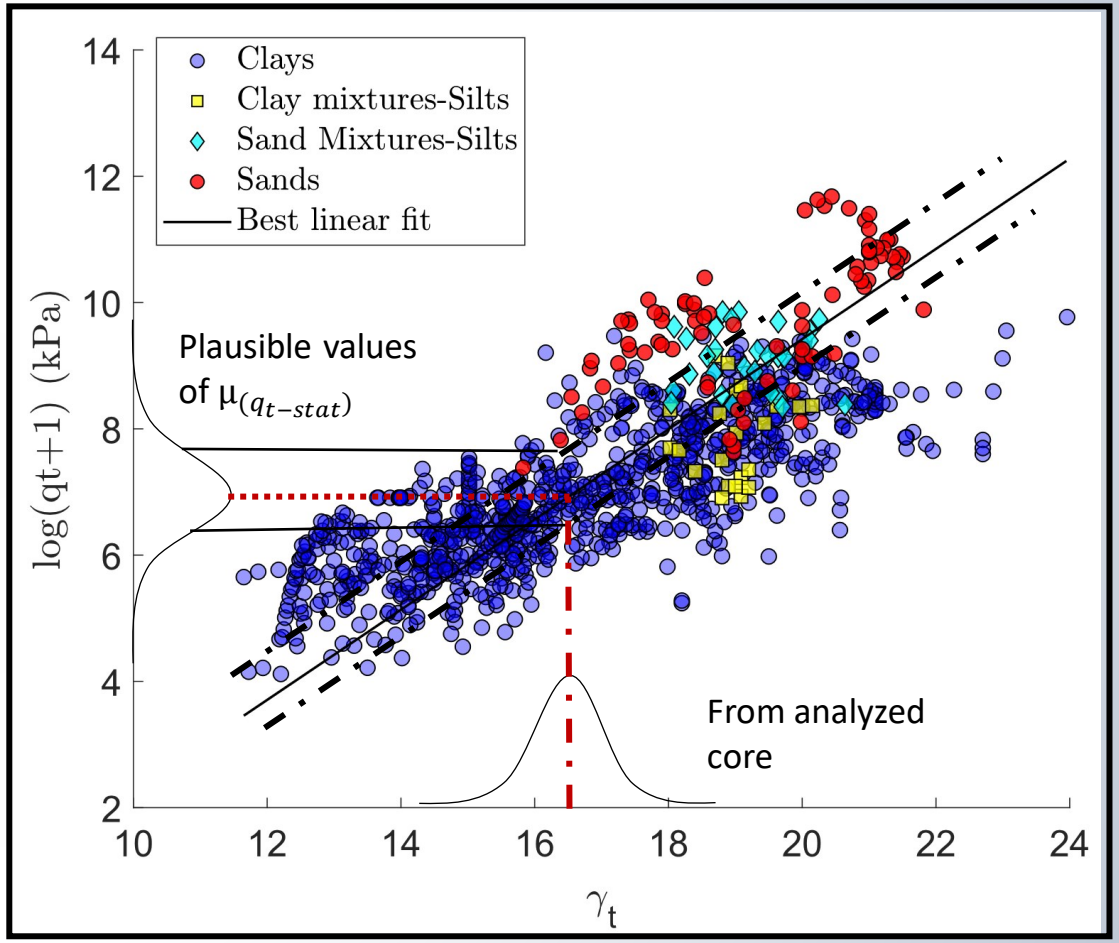


Bayesian Equivalent samples approach

(Zhang et al., 2012)

Methodology: Bayesian approach.

1st: Proposal distribution of $\mu_{(q_{t-stat})}$:
from Soil unit weight

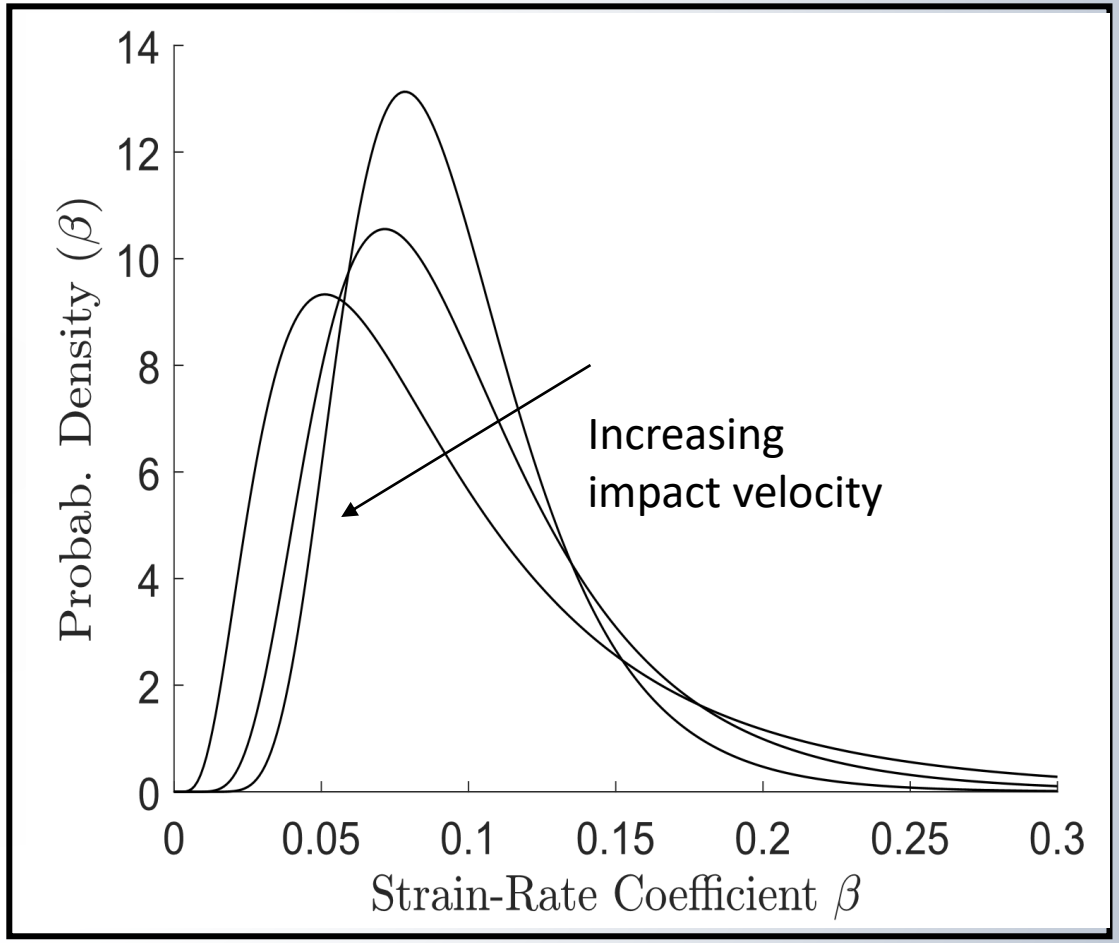


Methodology: Bayesian approach.

1st: Proposal distribution of $\mu_{(q_{t-stat})}$:
from Soil unit weight

2nd: Proposal distribution of $\boldsymbol{\beta}$

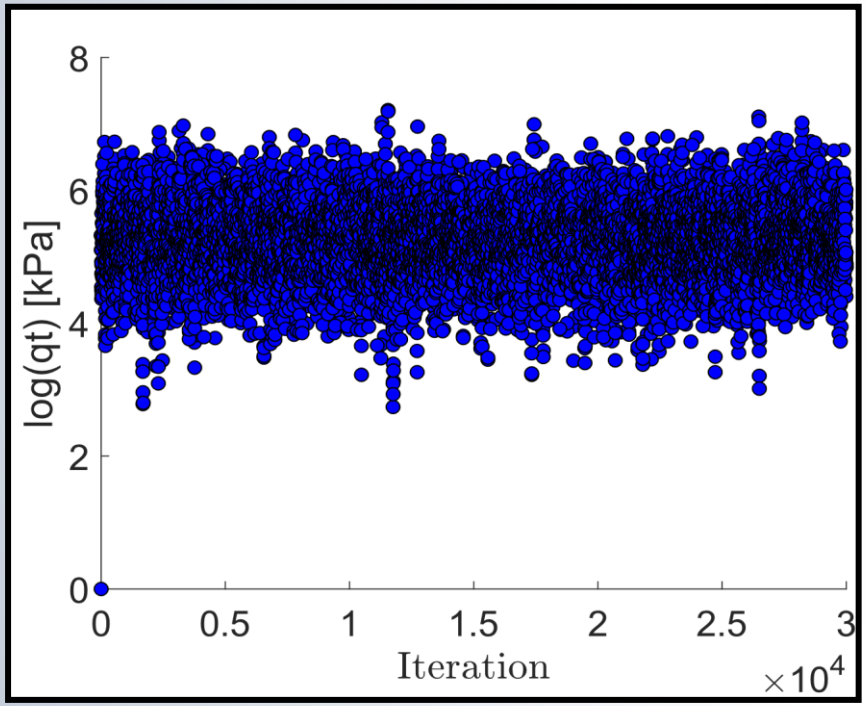
$\boldsymbol{\beta}$ (Impact velocity):
Lognormal distribution whose spread depend on impact velocity.



3rd: $f\ (\mu_{(q_{t-stat})}, \beta) = 0$ - Hybrid Markov Chain Montecarlo simulation.

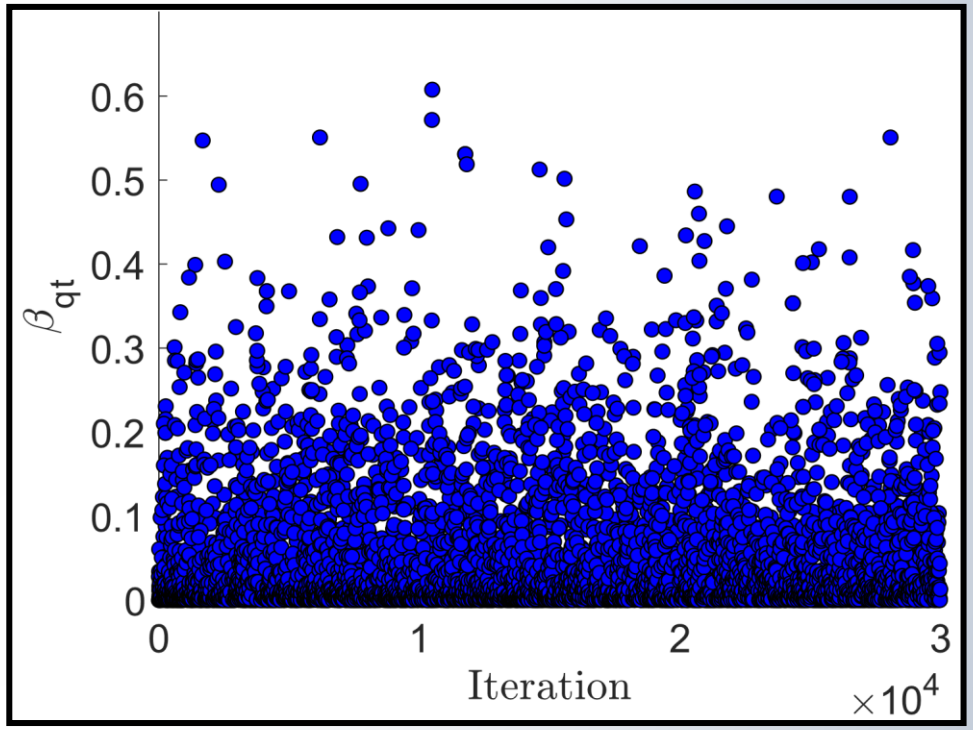
Generation of random $\mu_{(q_{t-stat})}$, β samples from their respective proposal distribution

35000 *Equivalent samples*:



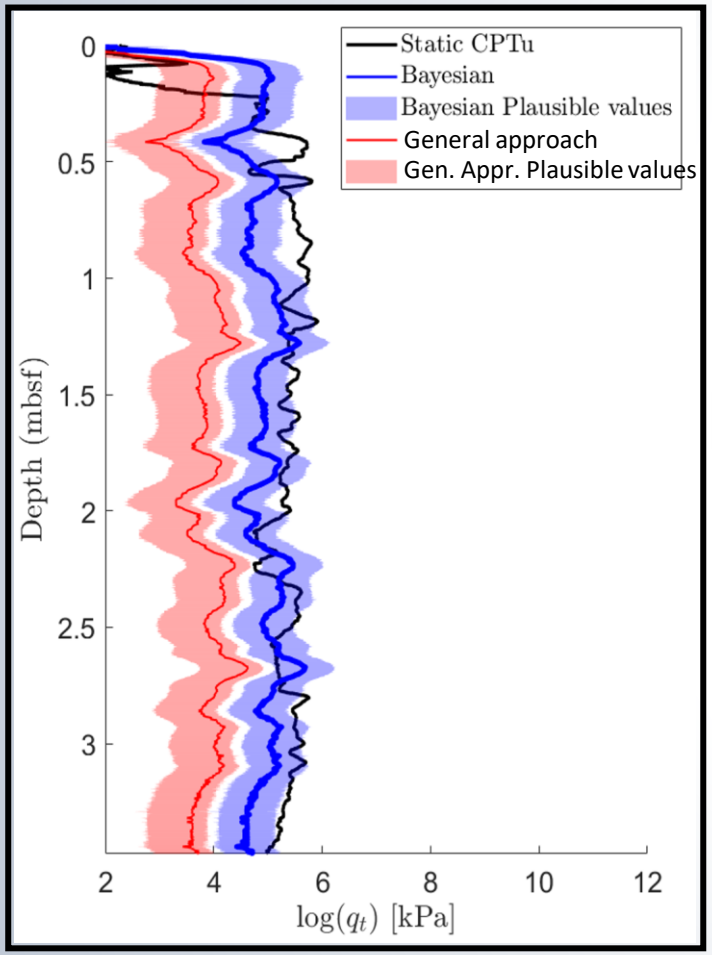
$\sigma_{(\mu(\boldsymbol{qt}))} = 0.7$
$\mu_{(\mu(\boldsymbol{qt}))} = 5.41$

35000 *Equivalent samples*:

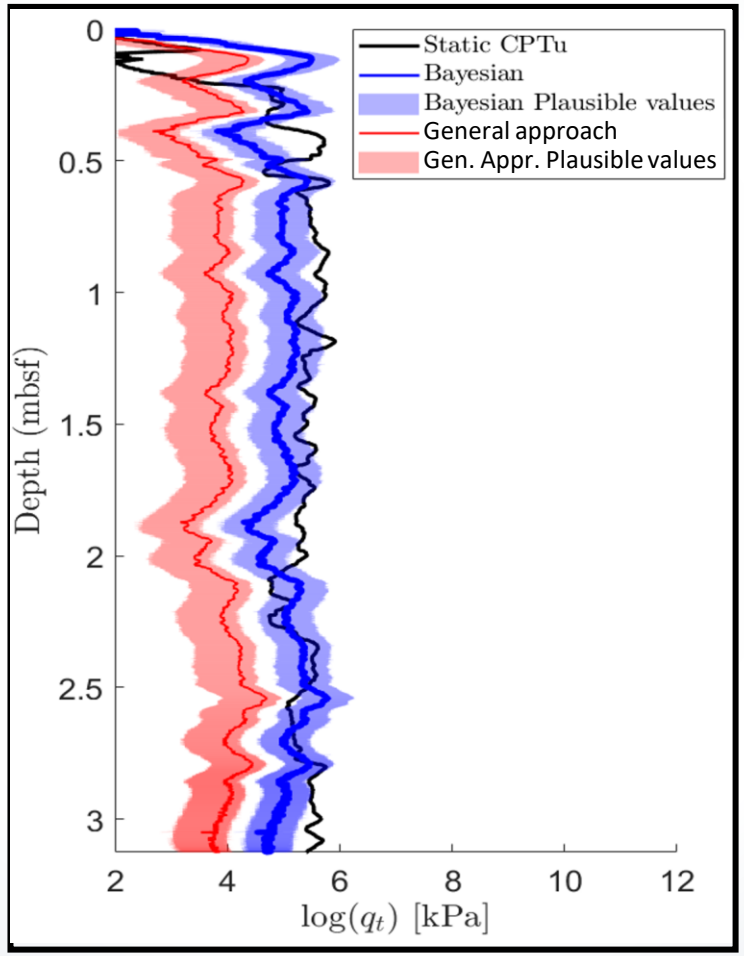


$\sigma_{(\boldsymbol{\beta})} = 0.04$
$\mu_{(\beta)} = 0.03$

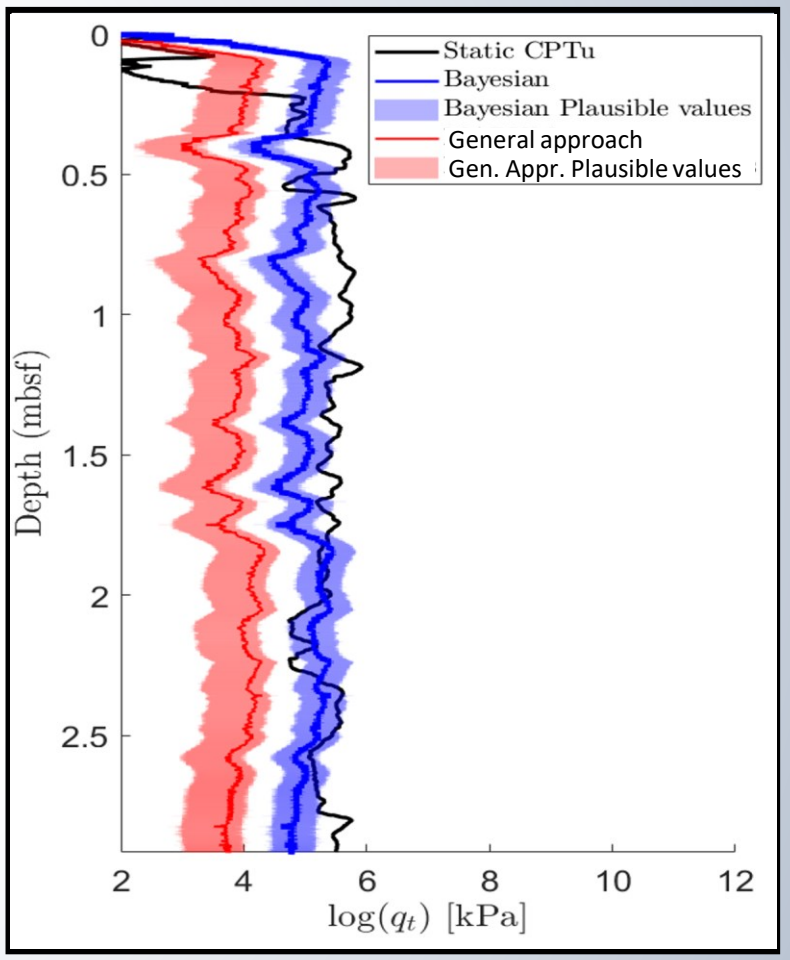
SW_16: Impact velocity 3 m/s



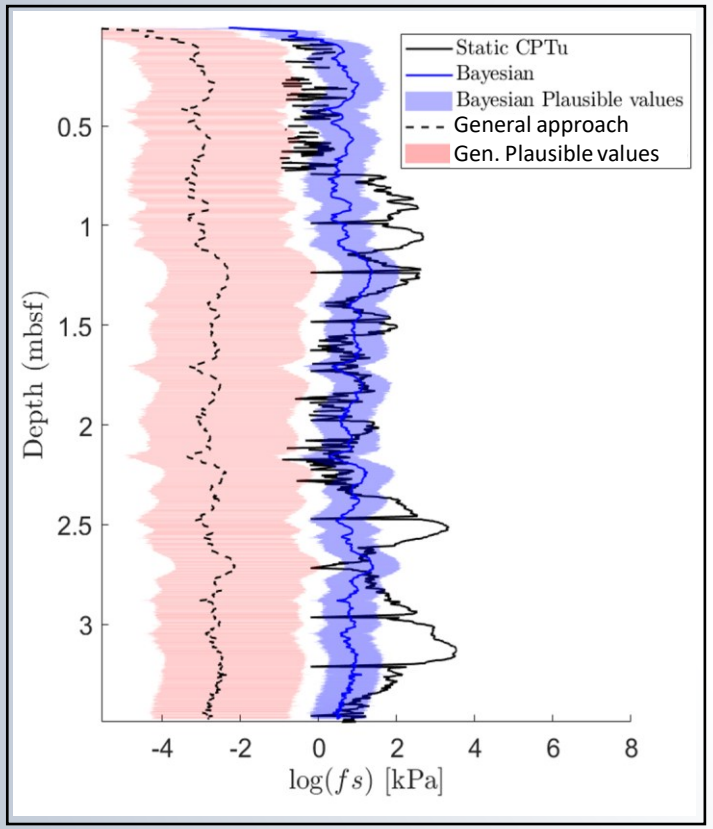
$SW8$: Impact velocity 1.1 m/s



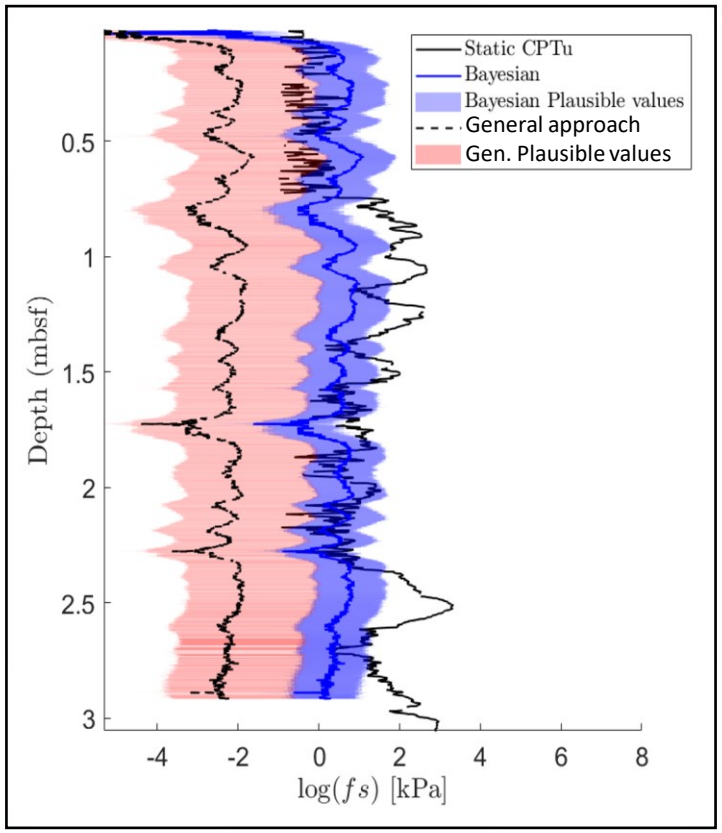
$SW2$: Impact velocity 0.5 m/s



SW_16: Impact velocity 3 m/s



$SW8$: Impact velocity 1.1 m/s



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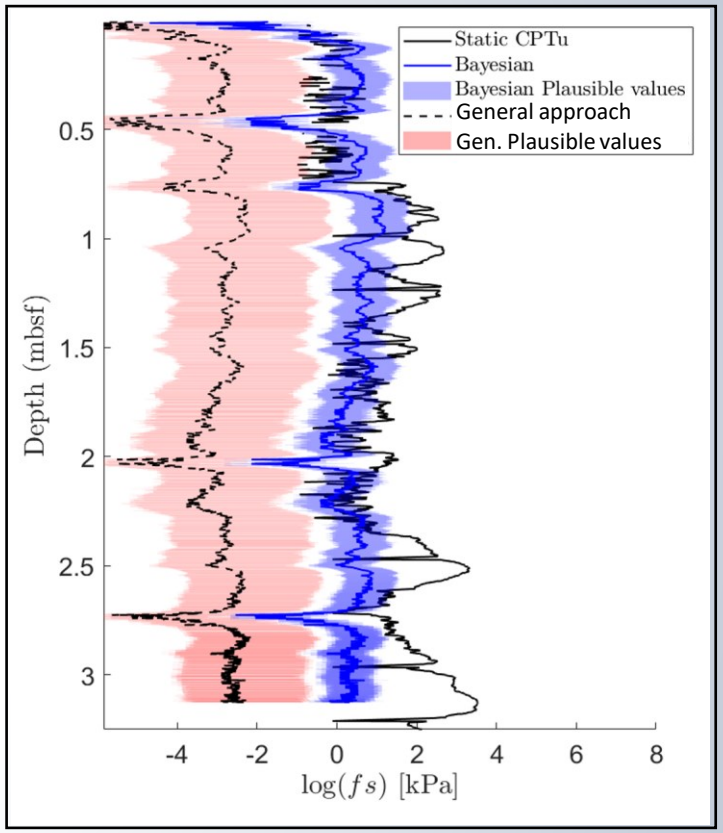

Conclusion:

- Good prediction of strain-rate coefficient β at different impact velocity from soil unit weight;
- The approach seems effective for simultaneously correction of dynamic cone tip resistance and sleeve friction;
- The approach is easily extendible for more complex model (e.g. adding overburden stress, drag force);

Possible development:

- Testing different strain-rate effect equations.
- Pore water pressure conversion.
- Direct conversion of undrained shear strength

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