Bayesian strain-rate correction for marine sediments characterization

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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.
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 $q_t$
$\neq$
Strain-rate effect $f_s$

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

\[ SRF = \left( \frac{v_{dyn}}{v_{stat}} \right)^\beta \]

\( v_{dyn} \) = penetration velocity of SW-CPTu;
\( v_{stat} \) = penetration velocity of static CPTu;
\( \beta \) = strain-rate coefficient

Simplistic model:

Converted \( q_{t \text{ static}} \) = \( q_{t \text{ dyn}} / SRF \)

Known parameters
Introduction: Strain-Rate Coefficient

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

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

**Literature**: empirical estimation of $\beta$: (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 $\beta$ prediction?

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

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

Mean value Mean value

$f\left(\mu(q_{t\text{-stat}}), \beta\right) = 0$

Unknown: $\mu(q_{t\text{-stat}}), \beta$
Study area:

Location: Trondheim, Norway.


Data acquired:
- Gravity cores
- 16 Dynamic CPTu
- Lab. Data (Soil unit weight)
Unknown: $\mu(q_{t-stat})$, $\beta$

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

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

Bayesian Equivalent samples approach
(Zhang et al., 2012)
Methodology: Bayesian approach.

1\textsuperscript{st}: Proposal distribution of $\mu(q_t-stat)$: from Soil unit weight
Methodology: Bayesian approach.

1\textsuperscript{st}: Proposal distribution of $\mu_{(q_t - \text{stat})}$: from Soil unit weight

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

$\beta$ (Impact velocity): Lognormal distribution whose spread depend on impact velocity.
3rd: \( f(\mu_{\text{qt-stat}}, \beta) = 0 \) - Hybrid Markov Chain Monte Carlo simulation.

Generation of random \( \mu_{\text{qt-stat}}, \beta \) samples from their respective proposal distribution

**35000 Equivalent samples:**

- \( \sigma(\mu_{\text{qt}}) = 0.7 \)
- \( \mu(\mu_{\text{qt}}) = 5.41 \)

**35000 Equivalent samples:**

- \( \sigma(\beta) = 0.04 \)
- \( \mu(\beta) = 0.03 \)

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**SW_16:** Impact velocity 3 m/s

**SW8:** Impact velocity 1.1 m/s

**SW2:** Impact velocity 0.5 m/s

General approach

Plausible values

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**SW_16**: Impact velocity 3 m/s

**SW8**: Impact velocity 1.1 m/s

**SW2**: Impact velocity 0.5 m/s
Conclusion:

- Good prediction of strain-rate coefficient $\beta$ 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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References


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