A New Probabilistic Common-Origin Approach to Assess Level-Ground Liquefaction Susceptibility and Triggering in all CPT-compatible Soils

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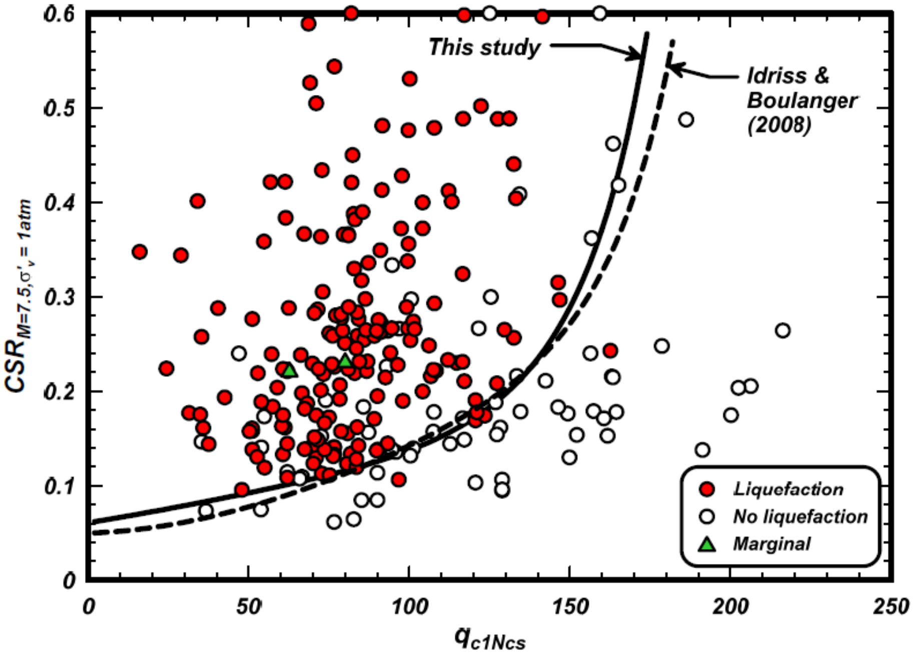
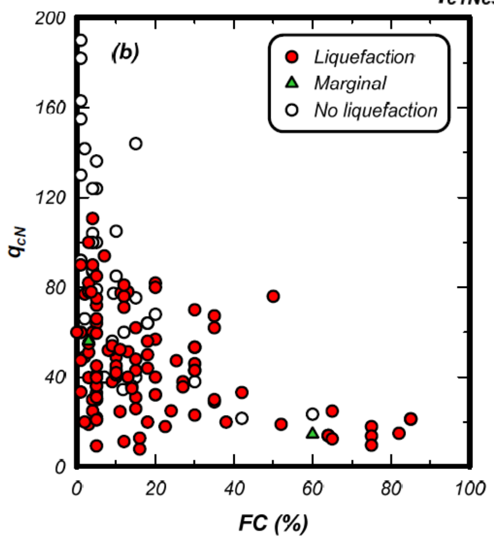
The motivation

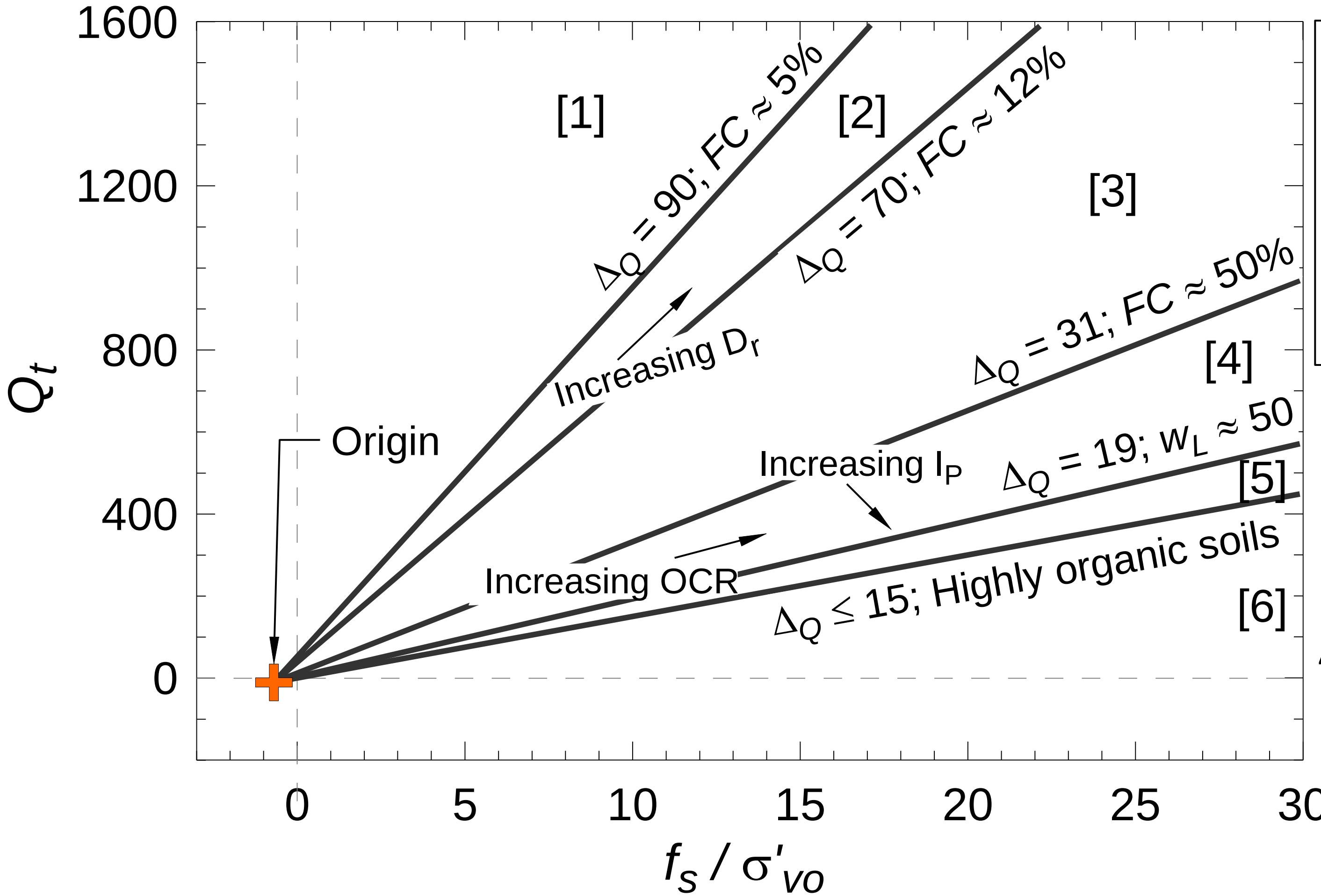




- *Conventional level-ground liquefaction triggering analysis deals chiefly with coarse-grained sands and silty sands*
- *253 cases in Boulanger & Idriss (2014) CPT database*
- *Only 15 with FC > 35%*
- *Nearly all fines reported as NP*
- *5 cases reported with PI ≤ 10*
- *Silty soils "adjusted" to equivalent clean sand penetration resistance using an uncertain fines content adjustment*

Boulanger and Idriss (2014)

Δ_Q approach for soil identification



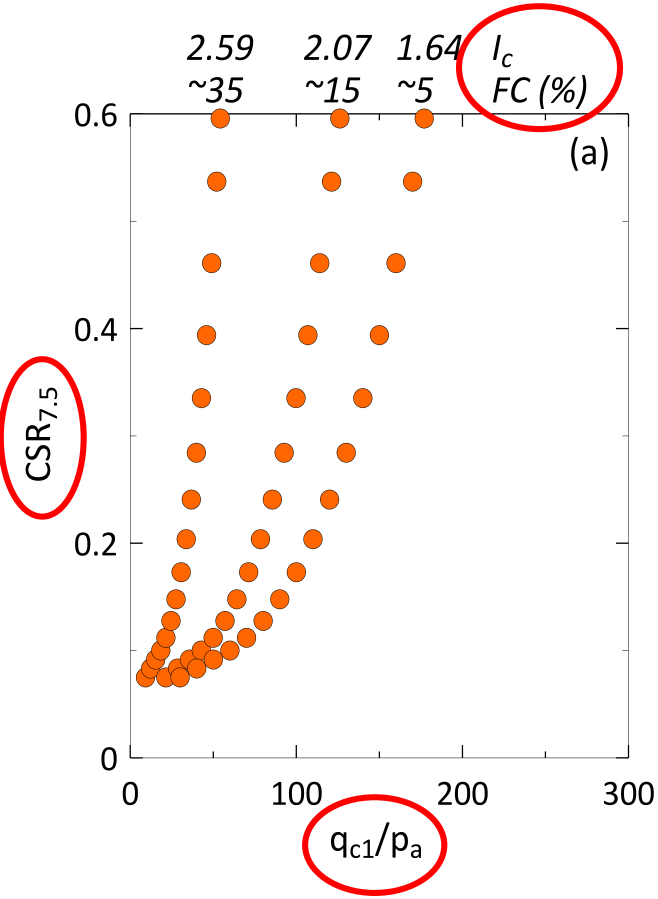
<u>Typical USCS</u>
[1] SP, SW
[2] SP-SM, SP-SC
[3] SM, SC, GM, GC
[4] ML, CL
[5] MH, CH
[6] OL, OH, Pt

Saye et al. (2017)

$$\Delta_Q = \frac{Q_t + 10}{\frac{f_s}{\sigma'_{v0}} + 0.67}$$

- *Δ_Q works for coarse sands through high-plasticity clays and peats*
- *Not affected by OCR*

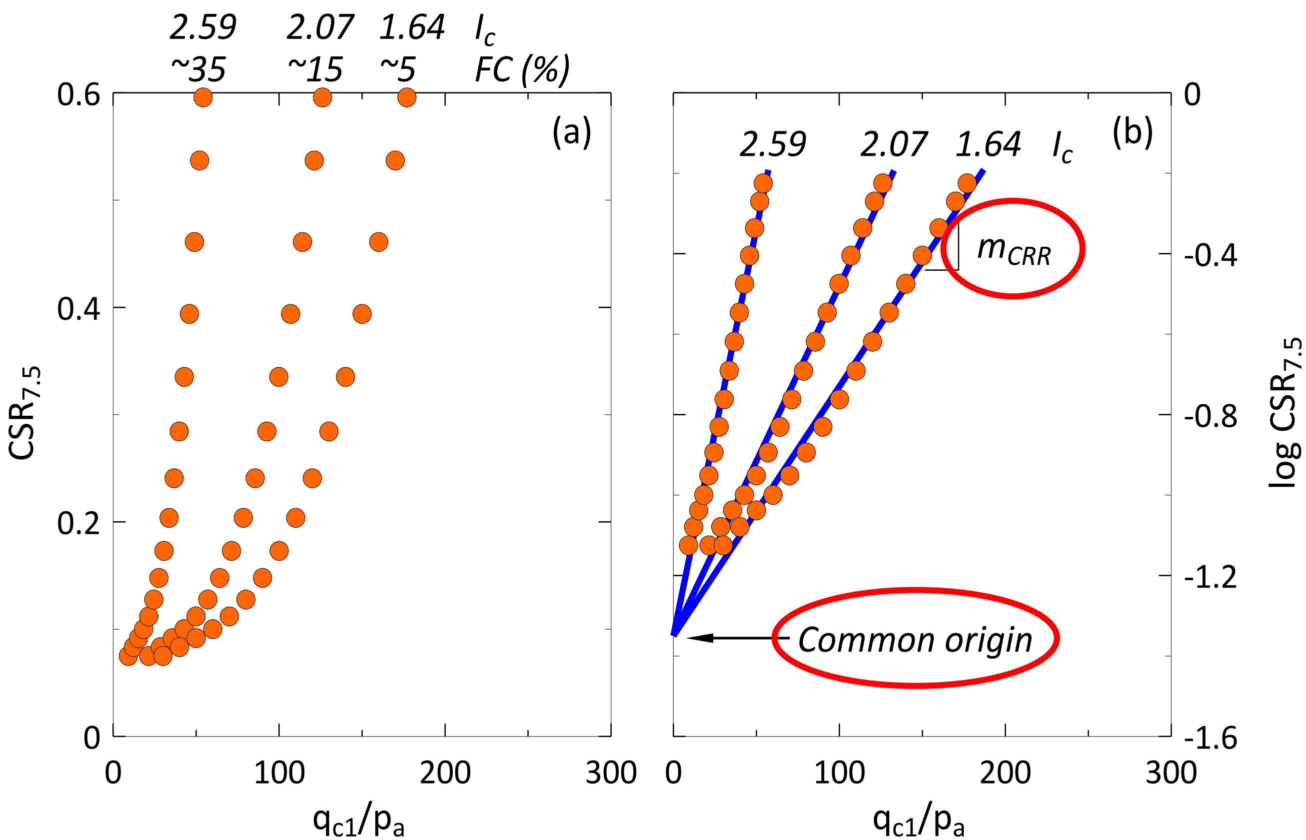
Issue 2: Covering all CPT-compatible soils



- *Liquefaction resistance curves involve 3 variables: seismic demand, soil density & soil type*

Saye et al. (2021)

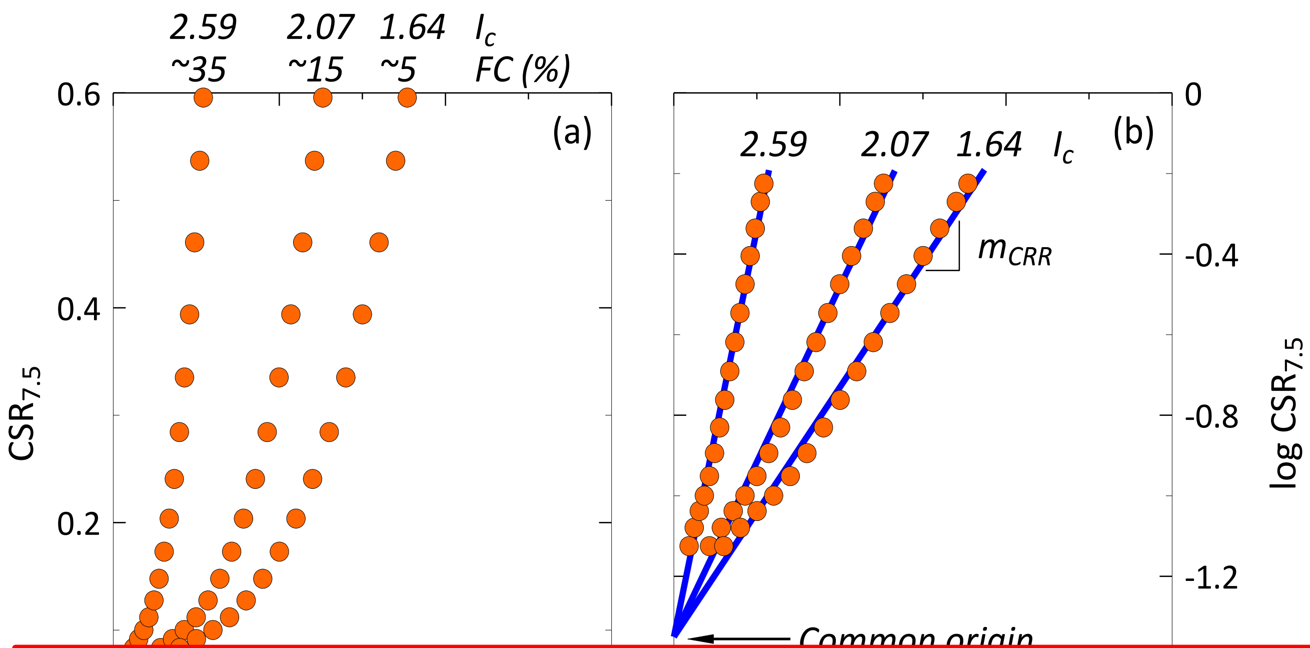
Issue 2: Covering all CPT-compatible soils



- *Liquefaction resistance curves involve 3 variables: seismic demand, soil density & soil type*
- *We can combine two variables, seismic demand and soil density into a single term, m_{CRR}*
- *The intercept in semi-log space is termed the "common origin"*

Saye et al. (2021)

Issue 2: Covering all CPT-compatible soils



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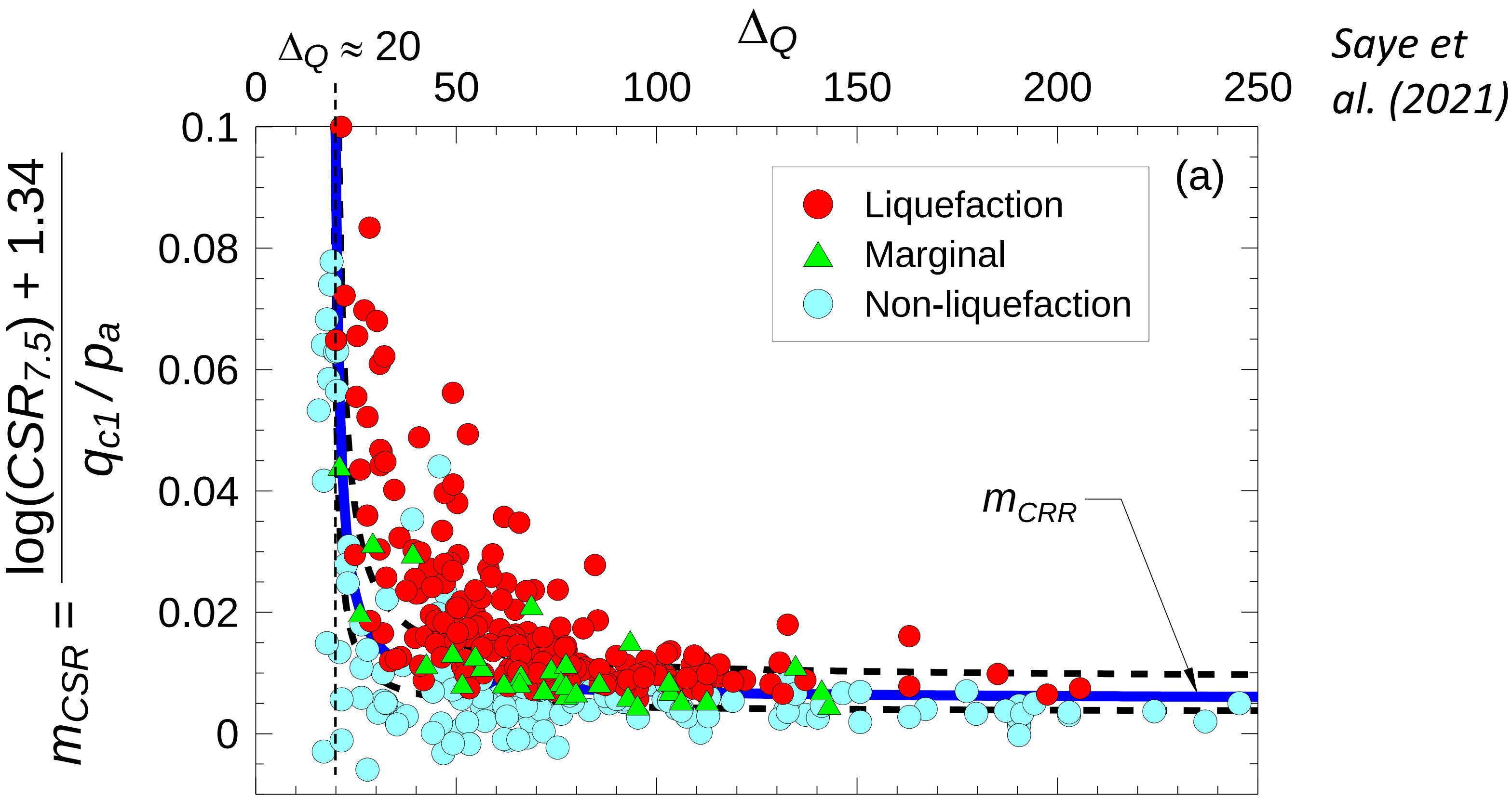
...intercept in ...i-log space is ...ned the ...mmon origin”

Reference	Common-origin $CRR_{7.5}$ intercept, C_o
Stark and Olson (1995)	-1.30
Robertson and Wride (1998)	-1.35
Moss et al. (2006)	-1.39
Boulanger and Idriss (2016)	-1.22

"Universal" common-origin, Δ_Q liquefaction triggering



- *Re-evaluated 401 CPT-based case records (252L : 149NL; **M**5.5 – 9.0)*
- *Case histories illustrate a clear separation based on m_{CSR} and Δ_Q*
- *Limiting Δ_Q corresponds to LL ≈ 30-40, PI ≈ 15-20, and D_{50} ≈ 0.03mm*
- *Limiting m_{CRR} corresponds to coarse-grained sands*

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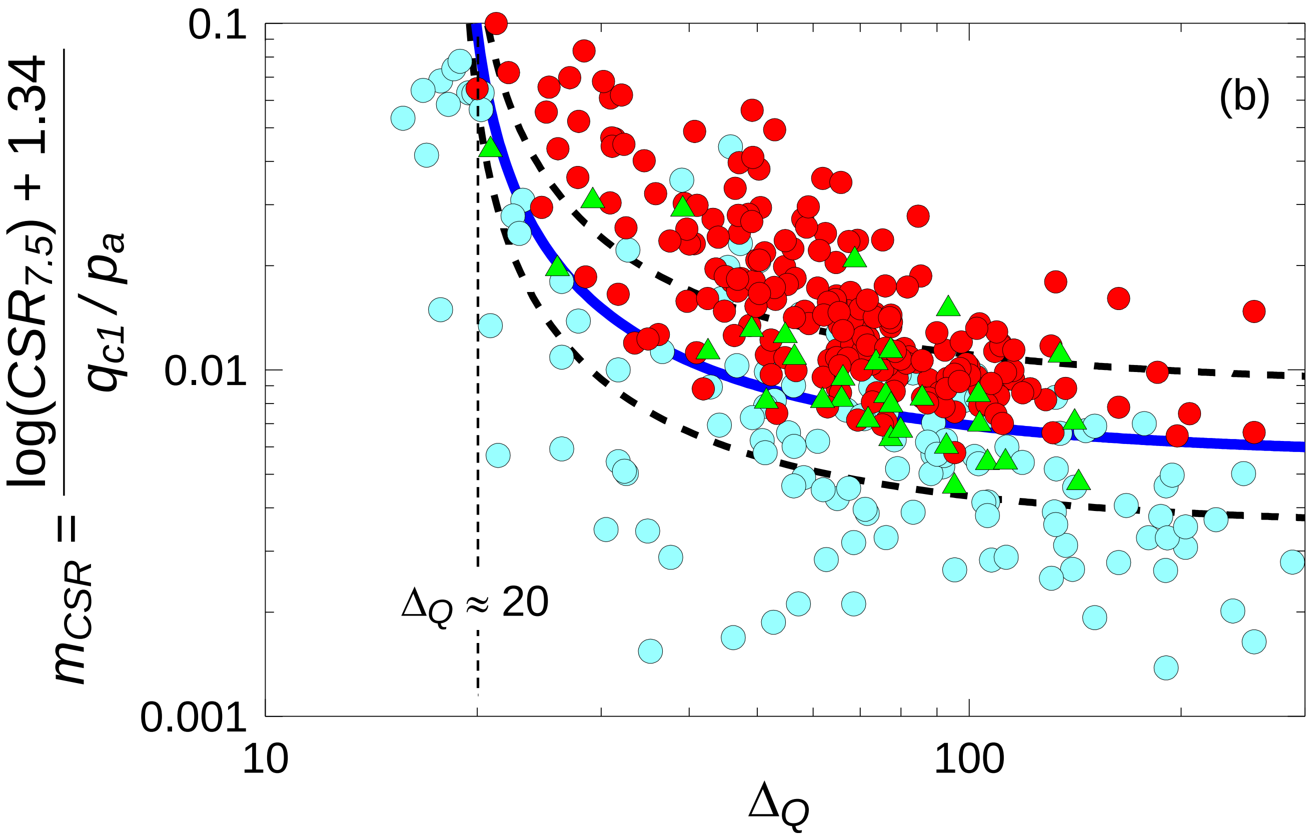

Saye et al. (2021)

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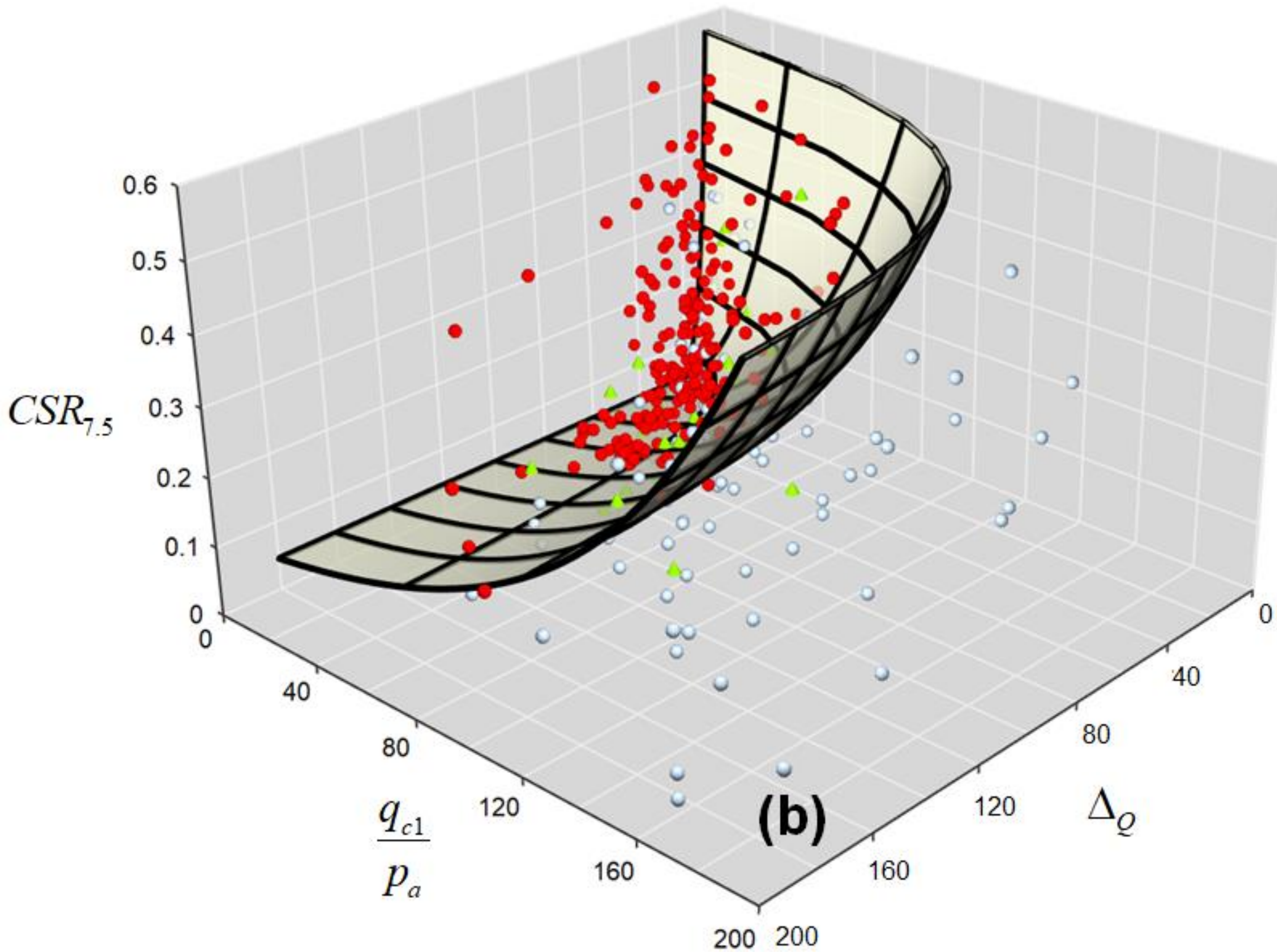


- *Previous figures represent three key variables presented in two-dimensional space to develop a single liquefaction resistance curve*
- *When separated and presented in three-dimensional space, the single curve becomes a three-dimensional surface*

Saye et al. (2021)

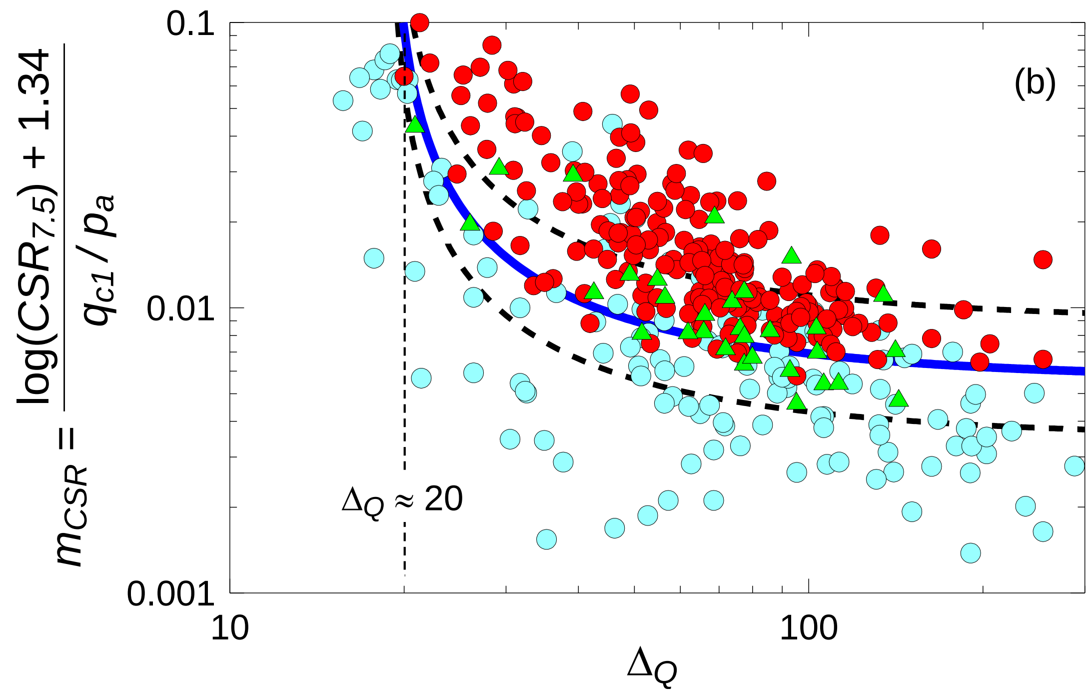
"Universal" common-origin, Δ_Q liquefaction triggering

Step 1: Compute Δ_Q for each row of CPT data

Step 2: Compute $CSR_{7.5}$ for each row (using Youd et al. 2001 r_d and MSF)

Step 3: Compute the median m_{CRR} for each layer:

$$m_{CRR} = \begin{cases} \dfrac{\Delta_Q}{178(\Delta_Q) - 3349} \leq 0.1 & for\ \Delta_Q \geq 20 \\ N/A \ldots not\ susceptible! & for\ \Delta_Q < 20 \end{cases}$$



Saye et al. (2021)

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“Universal” common-origin, Δ_Q liquefaction triggering

Step 4a: Compute $CRR_{7.5}$ and FS_L for each susceptible layer:

$$\log_{10} CRR_{7.5} = m_{CRR}\left(\frac{q_{c1}}{p_a}\right) - 1.34 + \sigma \cdot \Phi^{-1}[P_L]$$

$$\sigma = \begin{cases} 0.20 & \text{no uncertainty in } q_{c1} \text{ and } CSR_{7.5} \\ 0.24 & \text{uncertainty exists in } q_{c1} \text{ and } CSR_{7.5} \end{cases}$$

$$FS_L = \frac{CRR_{7.5}}{CSR_{7.5}} = 10\text{^}[\log_{10} CRR_{7.5} - \log_{10} CSR_{7.5}]$$

Recommended Values for Deterministic Calculation:

$$\sigma = 0.24$$

$$P_L = 0.35$$

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"Universal" common-origin, Δ_Q liquefaction triggering

Step 4b: Compute P_L for each susceptible layer:

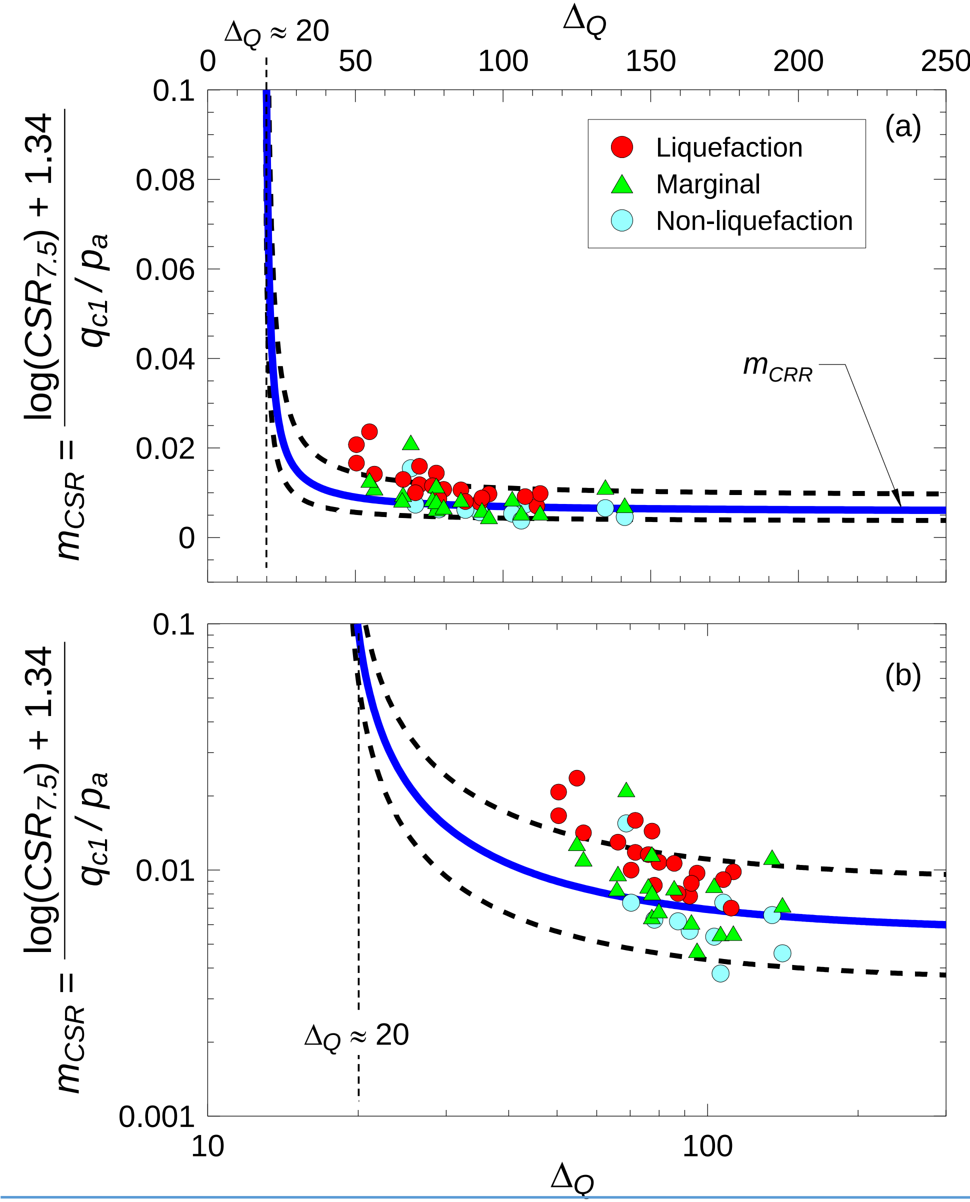
$$P_L = \Phi\left[\frac{\left(m_{CRR}\left(\frac{q_{c1}}{p_a}\right) - 1.34\right) - \log_{10} CSR_{7.5}}{\sigma}\right]$$

$$\sigma = \begin{cases} 0.20 & \textit{no uncertainty in } q_{c1} \textit{ and } CSR_{7.5} \\ 0.24 & \textit{uncertainty exists in } q_{c1} \textit{ and } CSR_{7.5} \end{cases}$$

Recommended for typical projects

Saye et al. (2021)

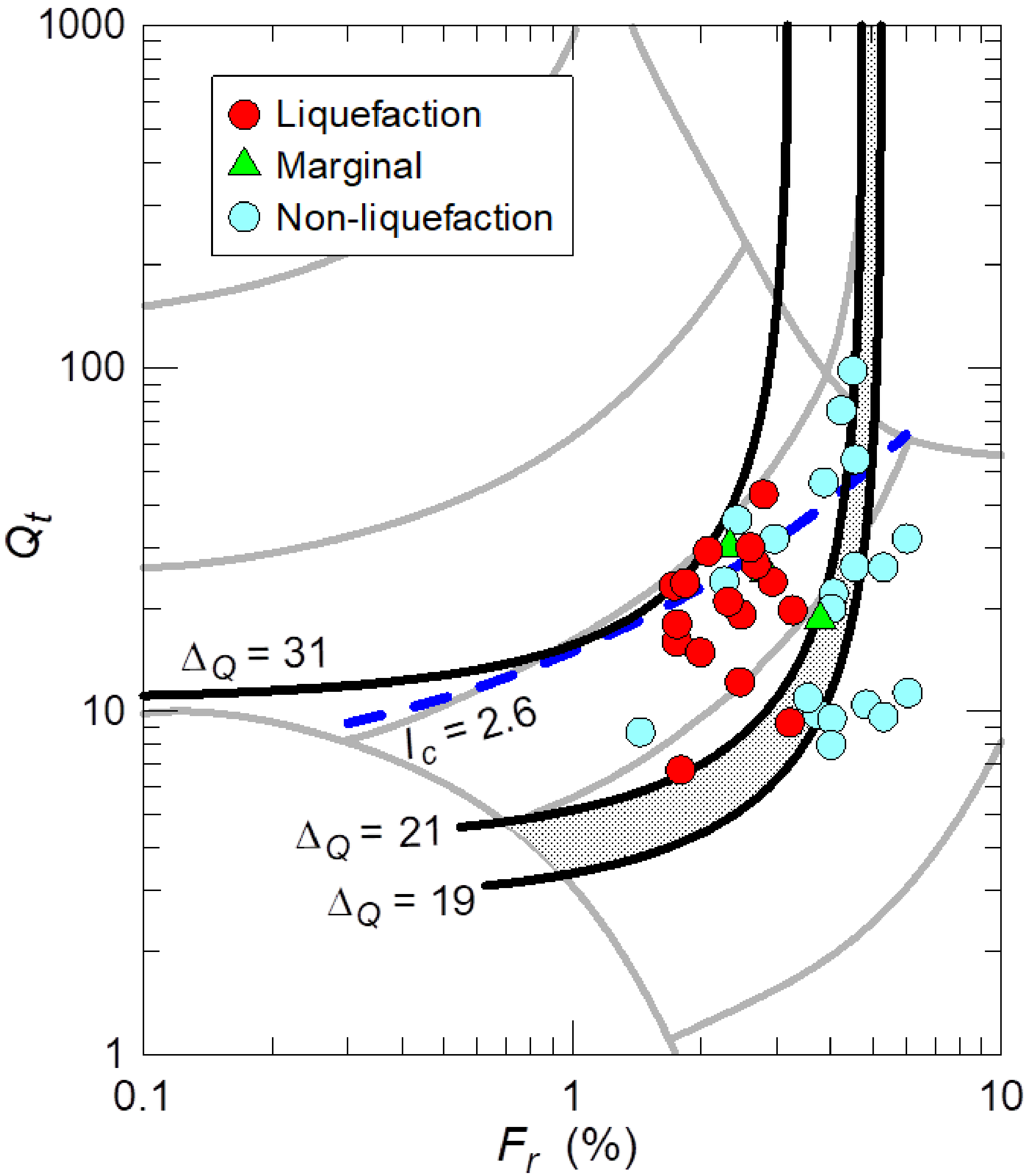
Does it work for clean & silty sand data?



- *Green et al. presented 25 "select" sites subjected to the 2010 Darfield (M7.1) and 2011 Christchurch (M6.2), New Zealand earthquakes*
- *Other liquefaction triggering methods have relatively poorly differentiated case records*
- *Common-origin, Δ_Q method misclassifies only 1 non-liquefaction case record*

Saye et al. (2021)

Does Δ_Q improve susceptibility classification of clays?



- *Robertson and Wride (1998) suggested that soils with $I_c > 2.6$ are not susceptible to "sand-like" liquefaction*
- *New database indicates many sites with $\Delta_Q < 31$ have manifest traditional liquefaction behavior*
- *$\Delta_Q \geq 20$ is reasonable threshold to identify non-sensitive, fine-grained soils that are susceptible to significant cyclic softening and liquefaction behavior*

Saye et al. (2021)

WARNING!!!

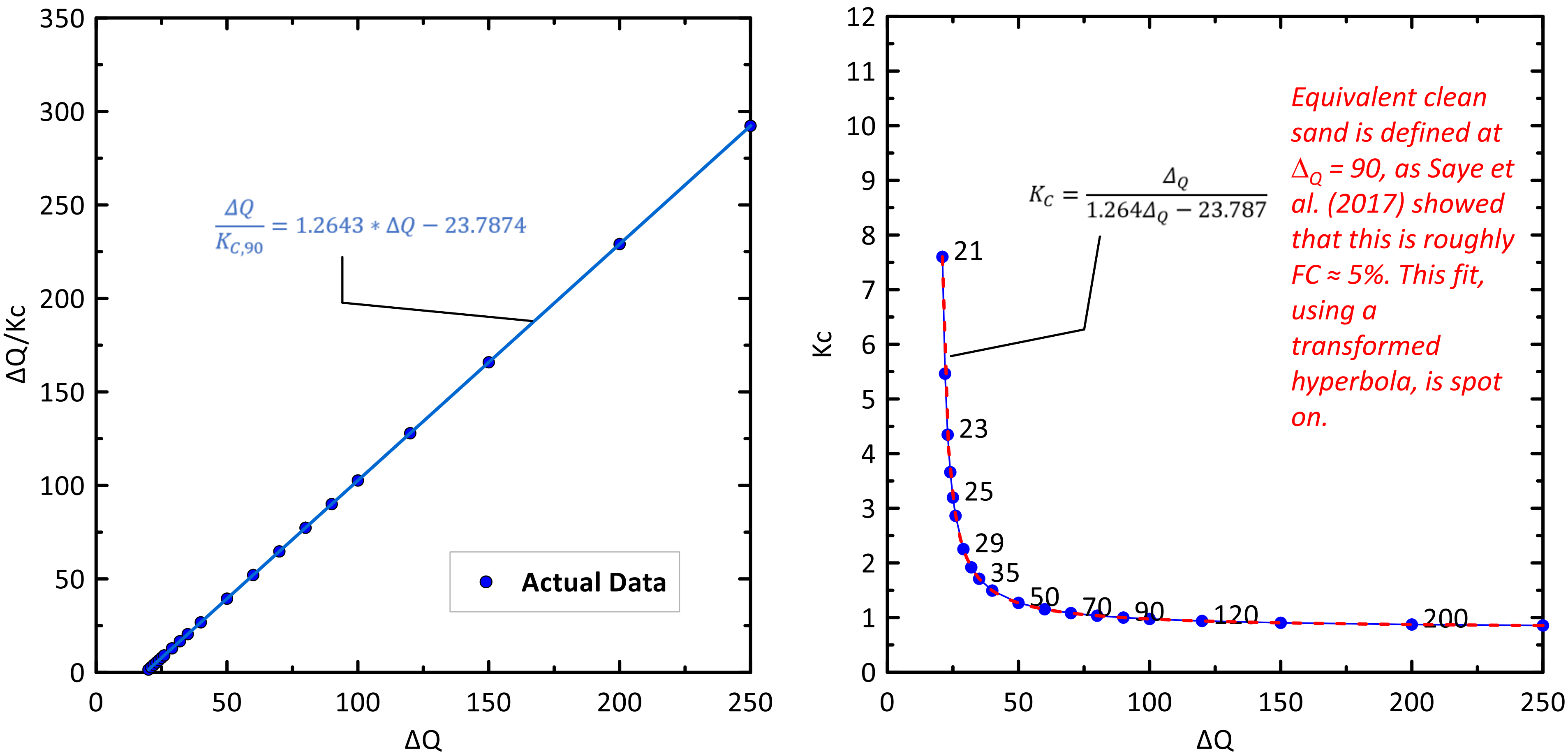
Do Not Use Saye et al. (2021) method to estimate post-liquefaction settlement (e.g., Ishihara and Yoshimine 1992) or lateral spread without first converting CPT tip resistance to DQ = 90 equivalent (….effectively a "clean-sand equivalent")

<u>Unless you do this, you will SEVERELY overestimate the predicted settlements and lateral spread displacements from the CPT data.</u>

Publication by Olson, Franke, Saye, and others is forthcoming…..

Courtesy of S. Olson..... "sneak peak" of the correction

Correction Factor 3



$$q_{c,\Delta_Q=90} = q_{c1,n} \times K_C$$

Overview

- *New procedure to simultaneously assess liquefaction susceptibility and triggering for nearly all CPT-compatible soils ranging from non-sensitive clays to clean sands*
- *Based on 401 case records with available CPT data*
- *Eliminates need to estimate the fines content of the soil*
- Δ_Q *=20 threshold corresponds approximately to LL≈30-40, PI≈15-20, and* D_{50}*≈0.03mm*
- *Differentiates the liquefaction resistance of clean sands based on CPT parameters rather than treating all clean sands identically*
- *Forthcoming clean-sand correction for* q_{c1N} *based on* Δ_Q *will reduce the tendency for common-origin method* FS_{liq} *to overpredict settlements and lateral disp.*

Thank you for your attention!

Questions?

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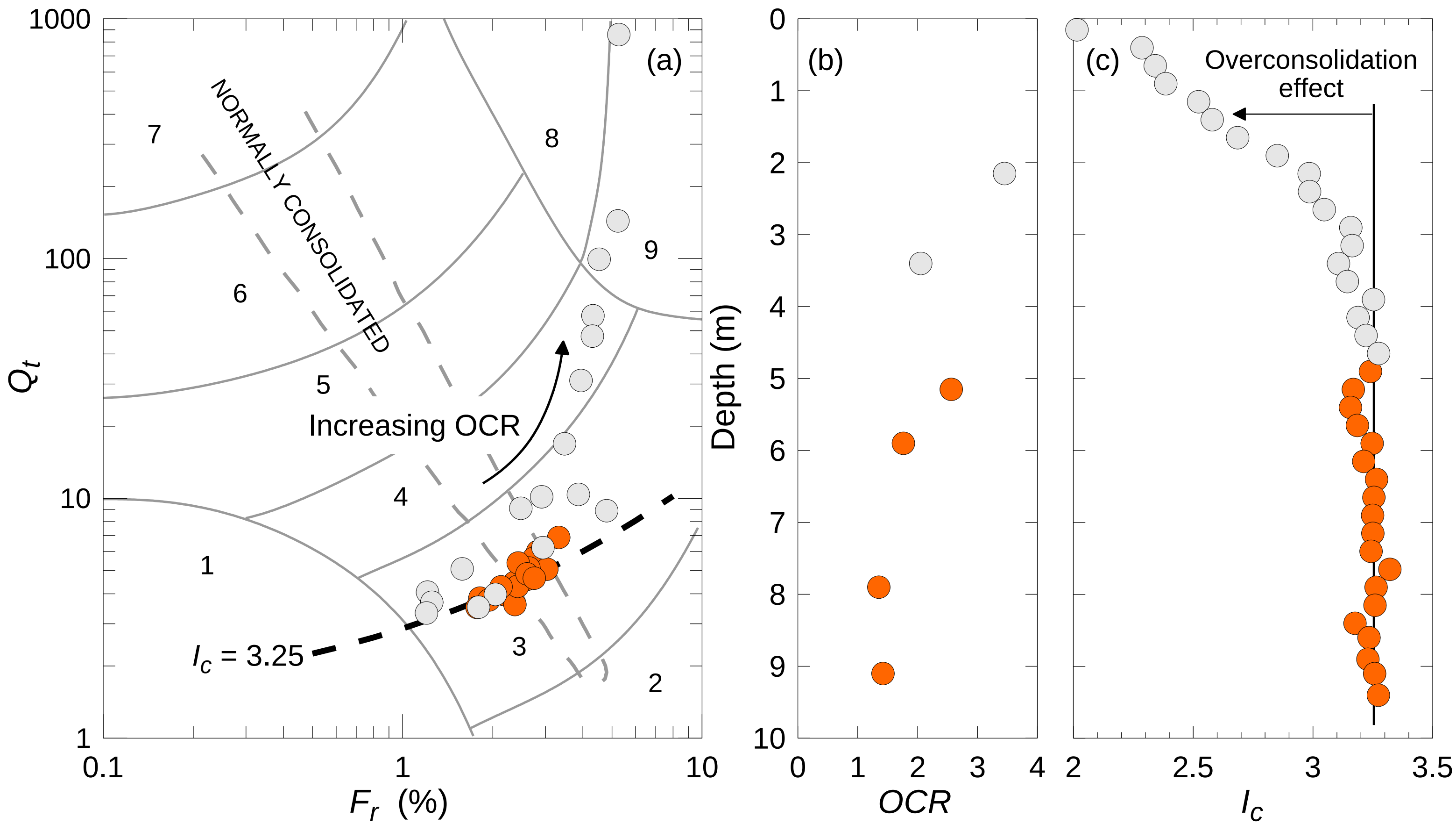
A "new" consistent method to interpret soil type



Saye et al. (2017)

- *Robertson I_c = 2 – 3.2 above 3m and I_c = 3.1 – 3.3 below ~3m*
- *Non-liquefiable based on I_c*
- *B-S = liquefiable; I-B = not liquefiable; R-W = not liq below ~1.5m*

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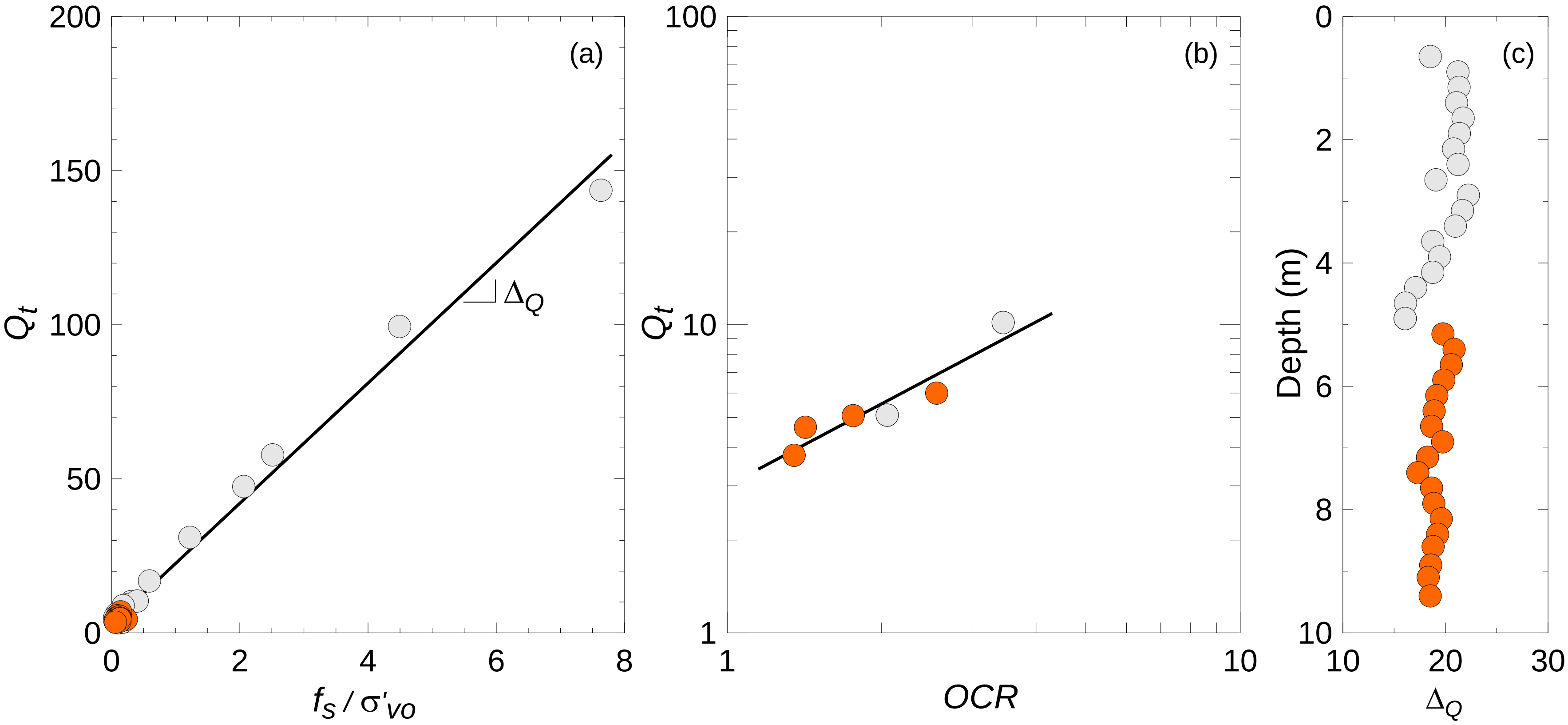
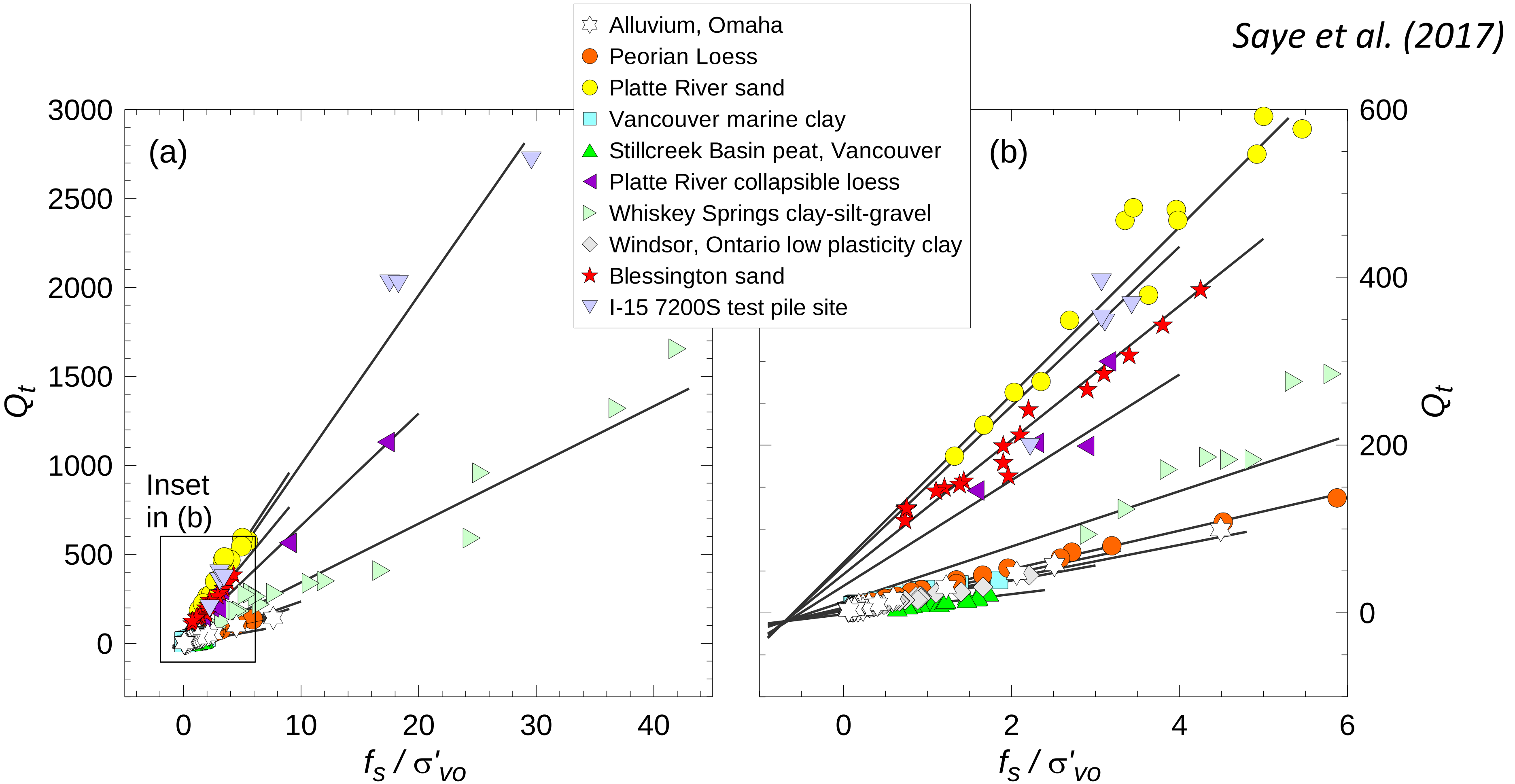
Δ_Q approach for soil identification



Saye et al. (2017)

- Δ_Q = *slope of* Q_t *and* f_s/σ'_{vo} *with offset origin*
- Δ_Q *is nearly constant with depth and unaffected by OCR*

Δ_Q approach for soil identification – multiple sites



- Δ_Q *works for coarse sands through high-plasticity clays and peats*
- *Not affected by OCR*