Laboratory database to examine the effects of confining pressure and static shear stress on liquefaction triggering

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Outline

- Background
- Data collection
- Computing CRR
- Effect of confining stress (K_σ)
- Effect of static shear stress (K_α)
- Future work

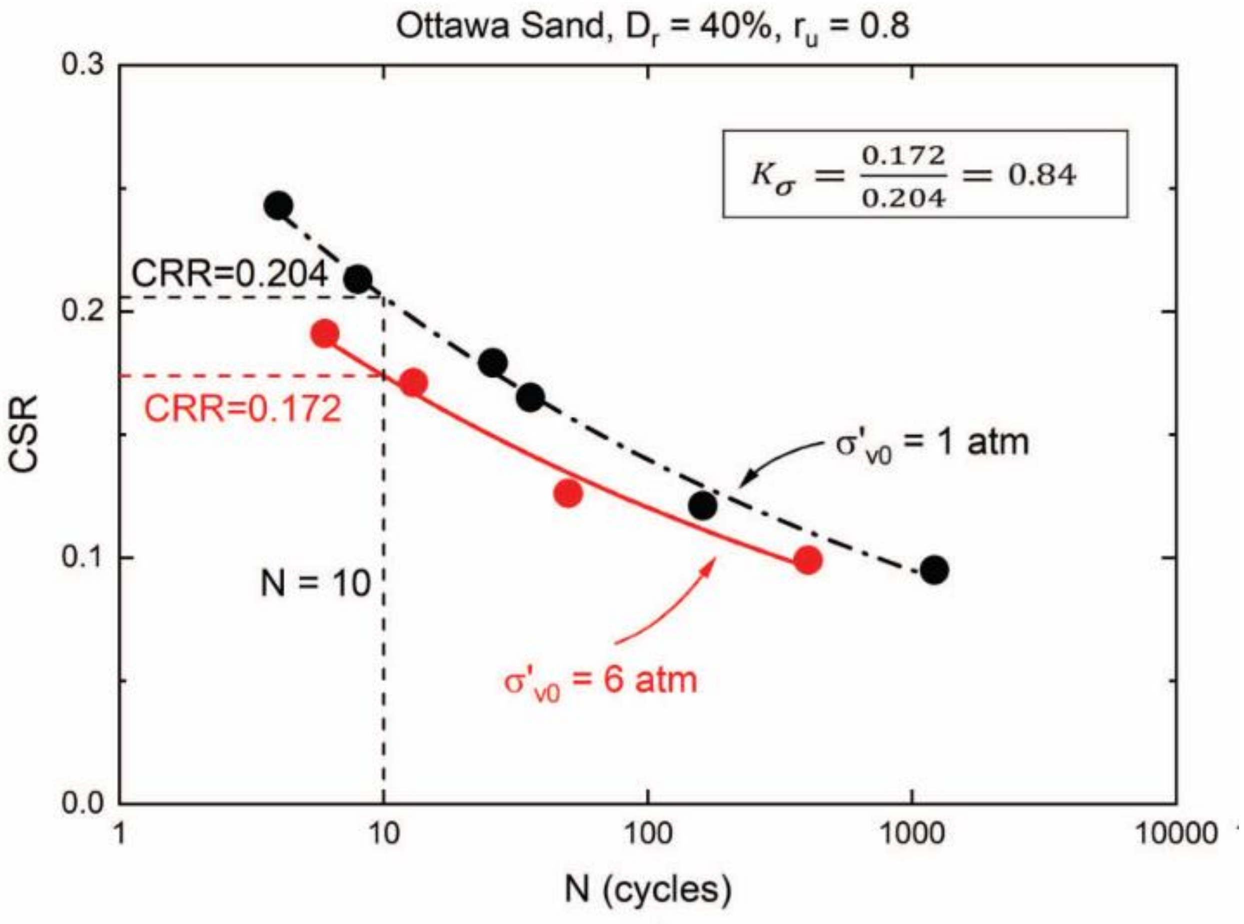
Background

- CSR = cyclic stress ratio

  CSR = $\Delta\tau/\sigma'_v$ (CDSS and CTS tests)

  CSR = $\Delta\sigma_d/(2\ p'_0)$ (CTRX tests)

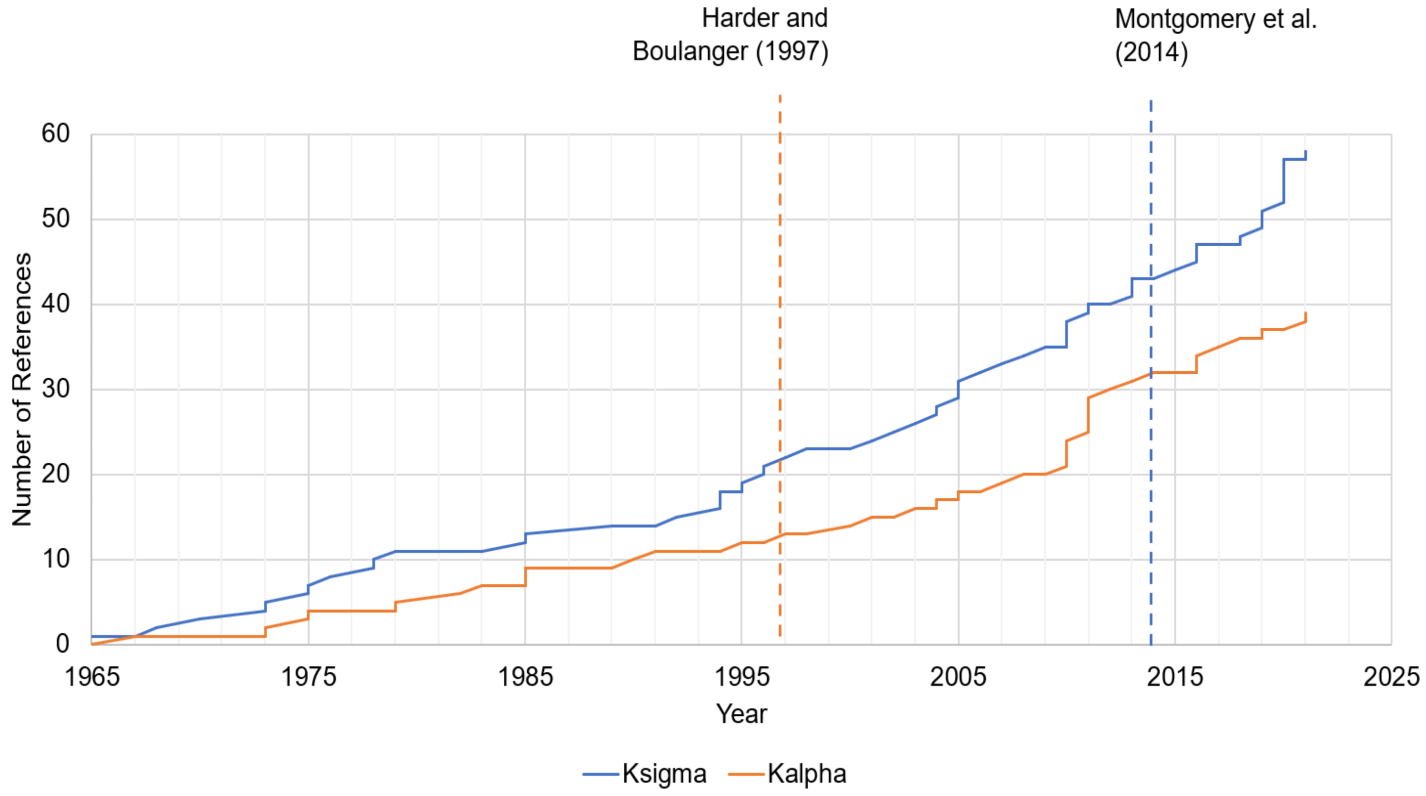
- CRR = cyclic resistance ratio. CSR for a given number of cycles (N_{ref})
- $K_\sigma = CRR_{\sigma\neq1} / CRR_{\sigma=1}$
- $K_\alpha = CRR_{\alpha\neq0} / CRR_{\alpha=0}$



Ni et al. (2020)

Data Collection

- Collected data from 63 different studies (35 with K_σ values and 36 with K_α values)
- Estimated K_σ and K_α values based on:
  - CSR vs N data
  - Reported CRR values
  - Reported K_σ and K_α values
- Only used studies with baseline conditions (σ'_c = 1 atm or τ_s = 0)
- Only used cyclic sinusoidal loading



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Data Collection

- Reference(s)
- Soil data
  - Soil name
  - FC, PI, LL
  - OCR
  - minimum and maximum void ratio
- Test data
  - Test type (CTRX, CDSS or CTS)
  - Preparation or sampling method
  - Liquefaction criterion
  - Loading frequency
- Soil state
  - relative density (Dr)
  - void ratio (e)
- Stresses
  - σ'_c (i.e., σ'_v for CDSS tests and both axial and radial stress for CTRX and CTS)
  - τ_s, α, or K_c
- Results
  - CSR vs N
  - CRR
  - K_σ and K_α

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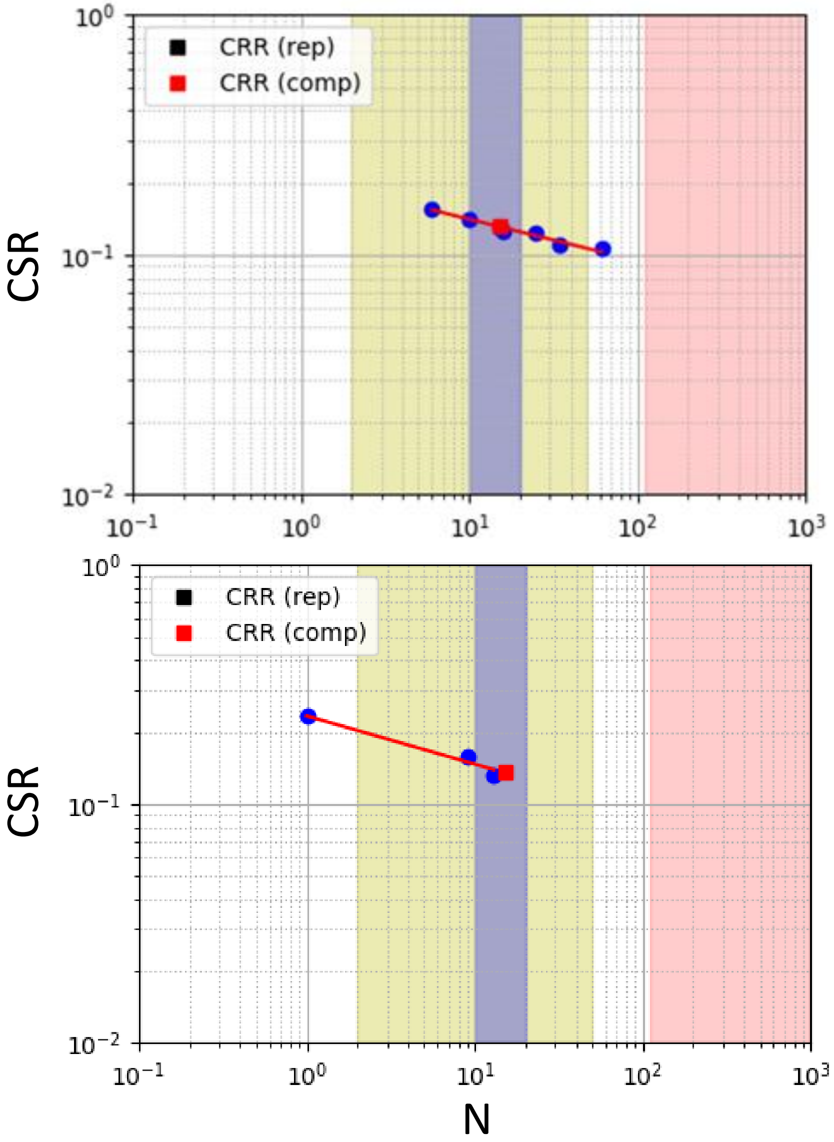
Computing CRR

- Fit a power law to the CSR v N data ($CSR = aN^{-b}$)
- Estimated CRR as CSR at $N_{ref} = 15$
- To avoid excessive extrapolation, imposed three constraints:
  - Range of data must contain or be within 5 cycles of N_{ref}
  - At least one test with N = 2-50
  - All tests with N > 110 not considered in regression
- Collected reported CRR values and adjusted to $N_{ref} = 15$
- Computed 707 CRR, collected 477 reported CRR, total of 960 unique CRR values



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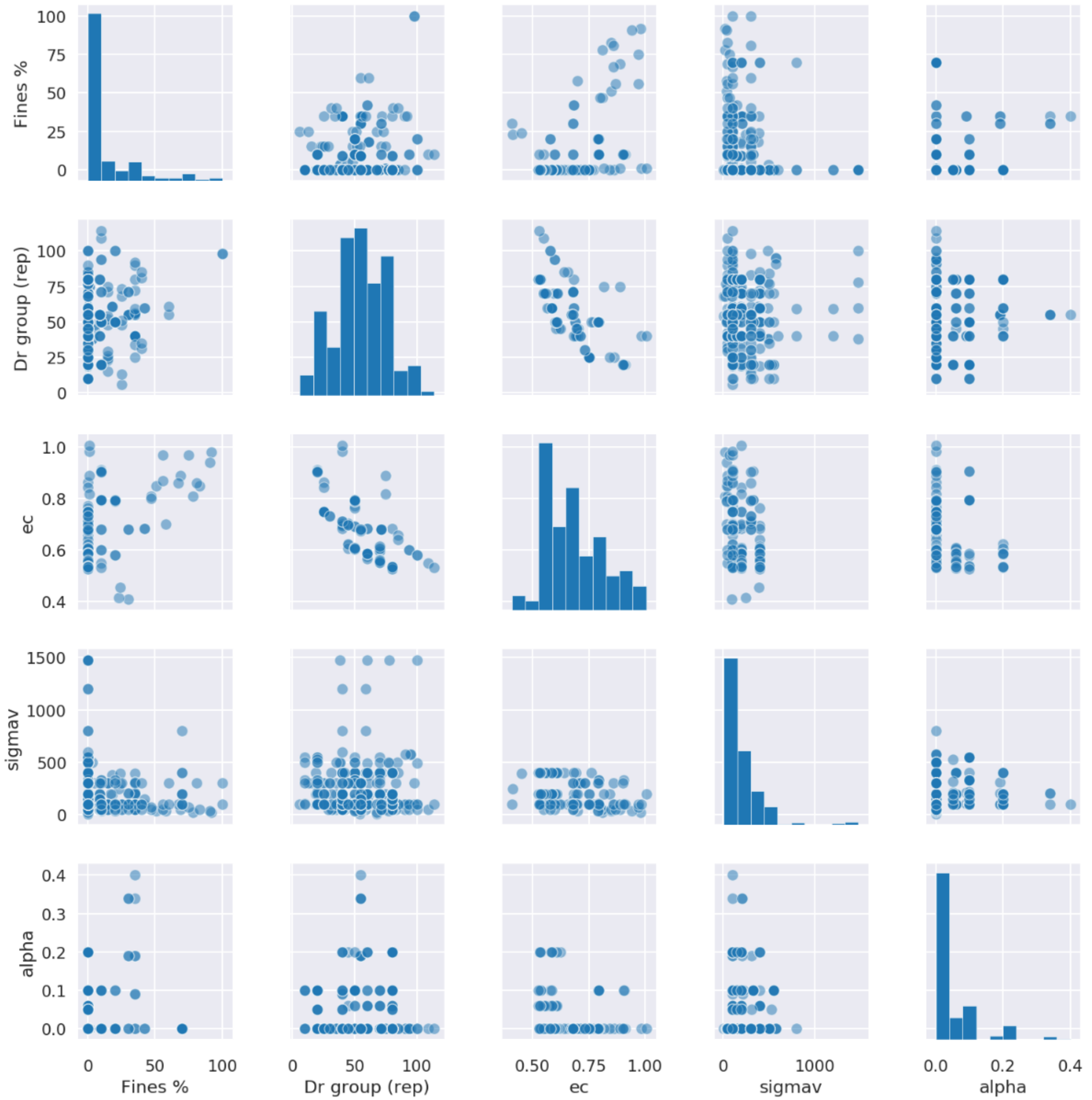
K_σ Database

- 231 unique K_σ values
- 147 from CTRX, 82 from CDSS and 2 CTS
- Most K_σ values are from soils with FC < 10%, Dr = 30–70%, σ'_v < 500 kPa, and $\alpha \approx 0$
- Only 20 K_σ values are from soils with PI > 0

Soil Name	Fines (%)	PI	Number of K_σ
Toyoura Sand	0	NP	34
Fraser River Sand	0	NP	30
Nakdong River Sand	0	NP	27
Silica Sand	0	NP	14
Adapazari Silts	Varies	Varies	12
M31 clean quartz sand	0	NP	9
Wenchuan Sand	0	NP	8
Sacramento River Sand	0	NP	8



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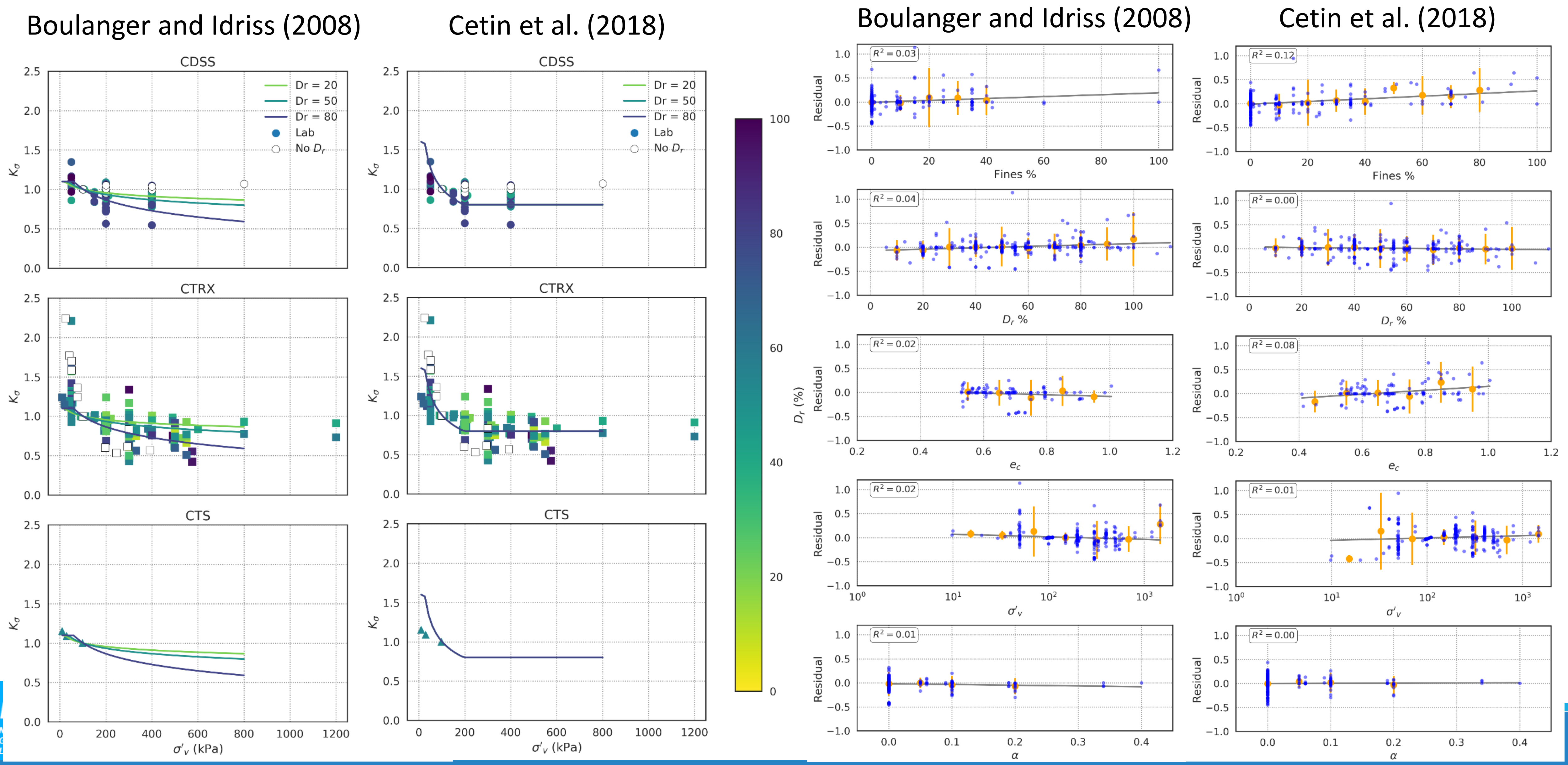
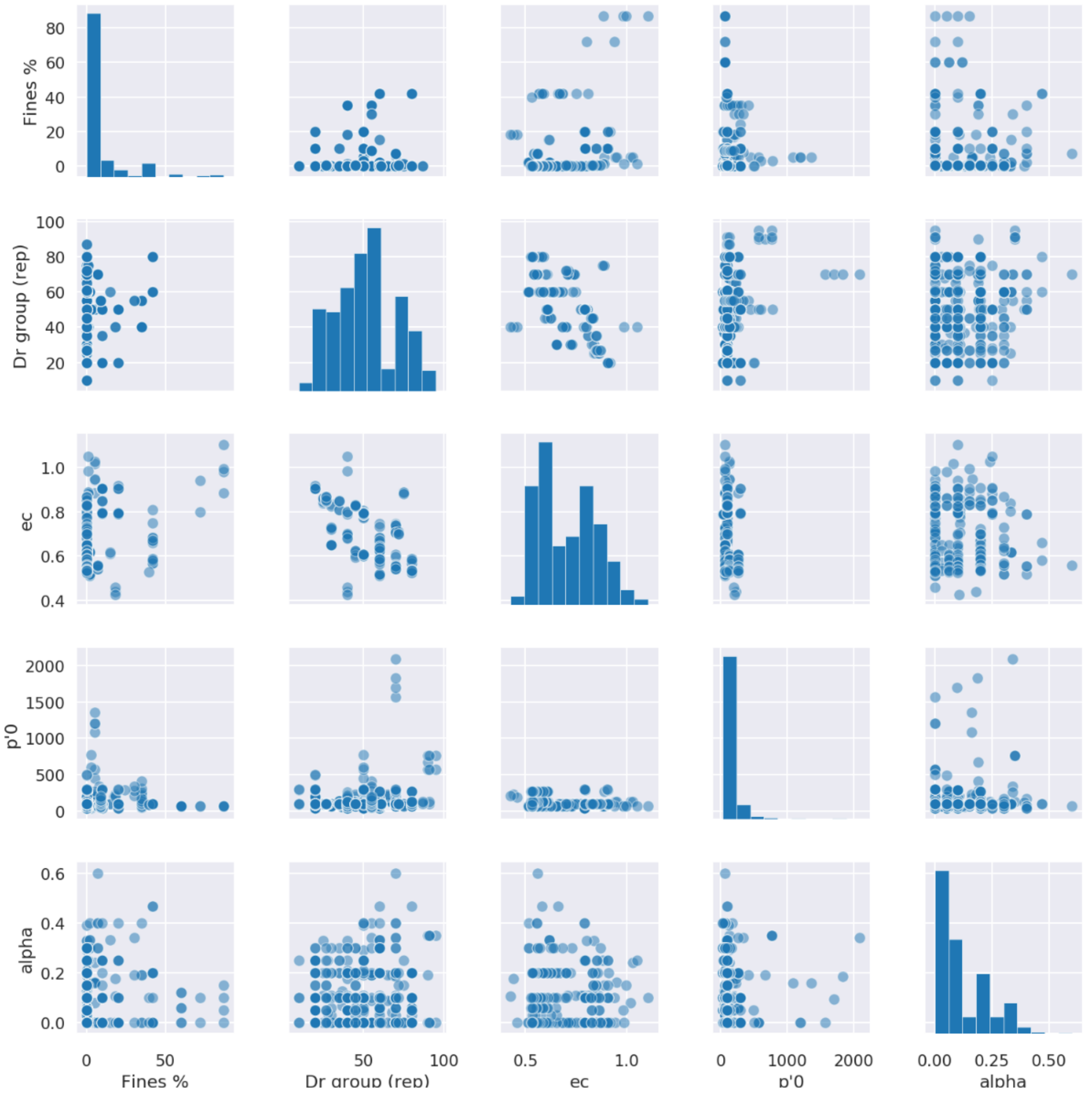
Comparison of K_σ data with models



K_α Database

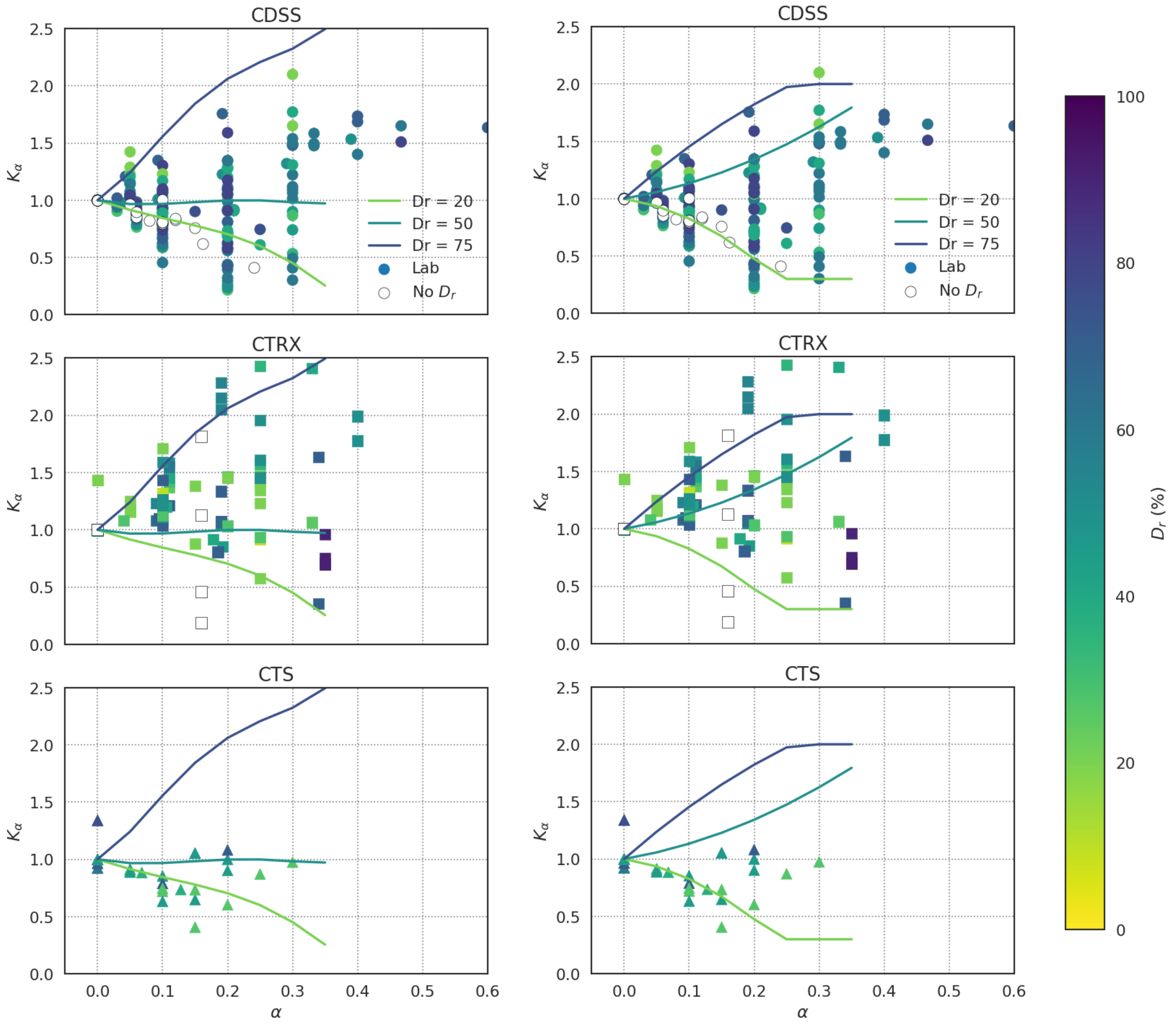
- 326 unique K_α values (either α or K_c)
- 277 unique K_α values (at least α known)
- 85 from CTRX, 170 from CDSS and 22 CTS
- Most K_α values are from soils with FC < 10%, Dr = 25–75%, σ'_v < 500 kPa, and α = 0-0.3
- Only 20 K_σ values are from soils with PI > 0

Soil Name	Fines (%)	PI	Number of K_σ
Toyoura Sand	0	NP	47
Silica Sand	0	NP	43
Babolsar Sand	0	NP	32
Fraser River Sand	0	NP	27
Nakdong River Sand	0	NP	18
Ottawa Sand	0	NP	13
Toyoura Sand + silt	10	NP	12
Sacramento River Sand	0	NP	12

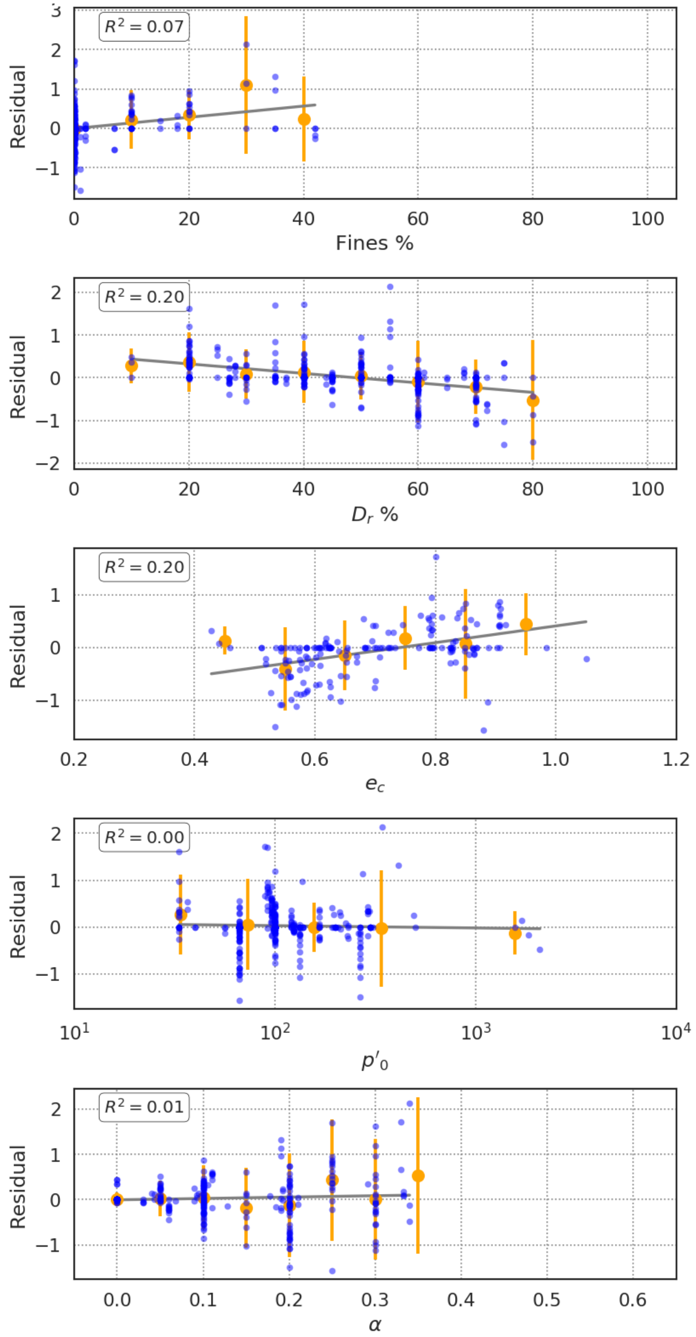


Comparison of K_α data with models

Boulanger (2003) Seed and Harder (1990)



Boulanger (2003)



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Future Work

- How to combine soils with high fines and no Dr with soils with low fines (critical state framework, void ratio, something else?)
- Compile critical state data
- How to properly combine CTRX and CDSS tests (stress invariant CSR?)
- Adjustments to K_σ at high confining pressures for particle breakage (or low confining pressures for weak soils, e.g. calcareous sands)
- Estimate K_σ and K_α when no CRR values are available for baseline conditions
- Explore other uses of the database (e.g. laboratory based liquefaction triggering curve)

Conclusions

- Compiled a database of 231 unique K_σ values and 326 unique K_α values with a wide range of soil and state parameters
- No clear bias or trend when comparing available models to the database
  - Significant scatter in the residuals
  - Small trend with fines content and K_σ residual for Cetin et al. (2018)
  - Small trend with Dr and K_α residual for Boulanger et al. (2003)
- No clear trend with effect of preparation method
- Database will be made available on DesignSafe
- Many opportunities for future research!