Klohn Crippen Berger

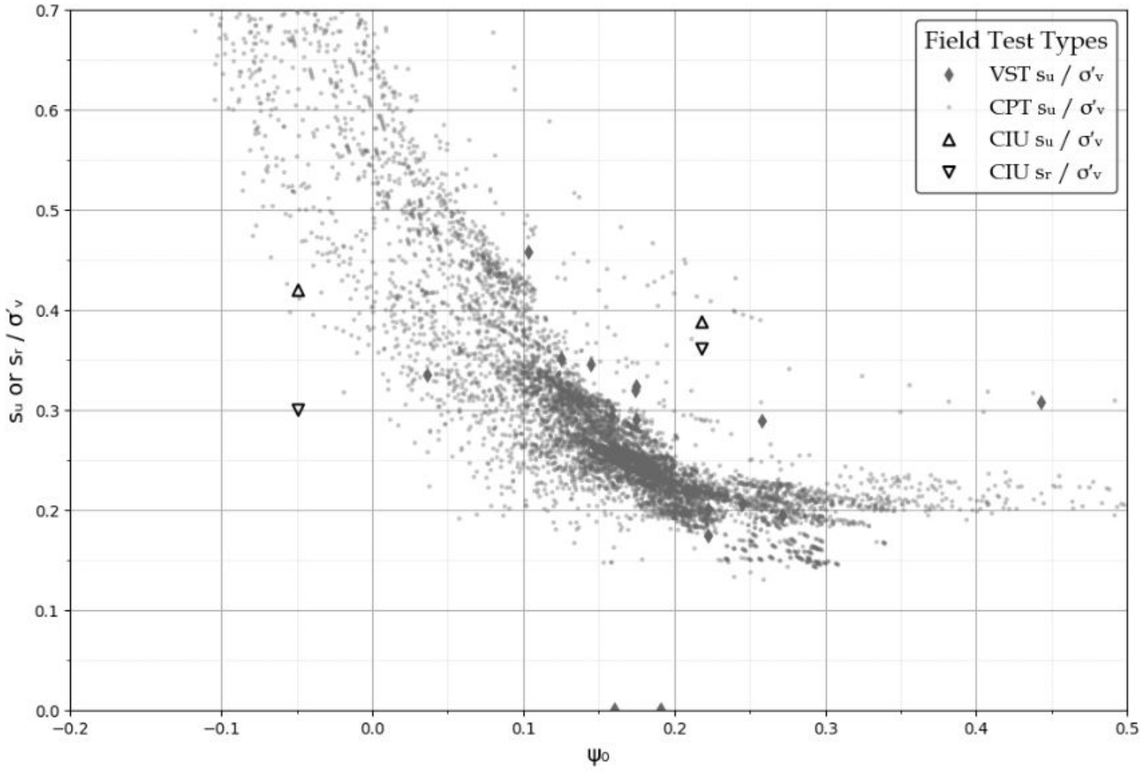
UNDRAINED SHEAR STRENGTH SELECTION WITHIN A CRITICAL STATE FRAMEWORK

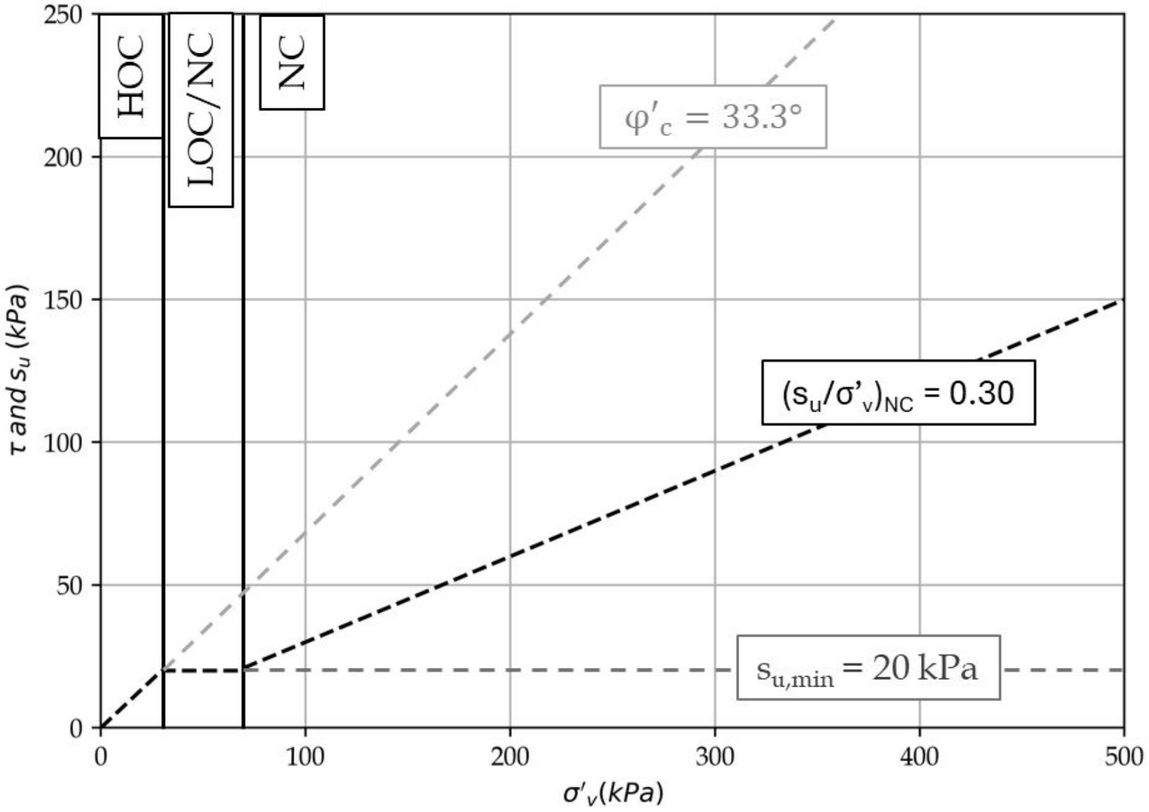
L.H. Kirsten, H.A. Brandão, F. Dan Walsh and L. Murray

March 2026

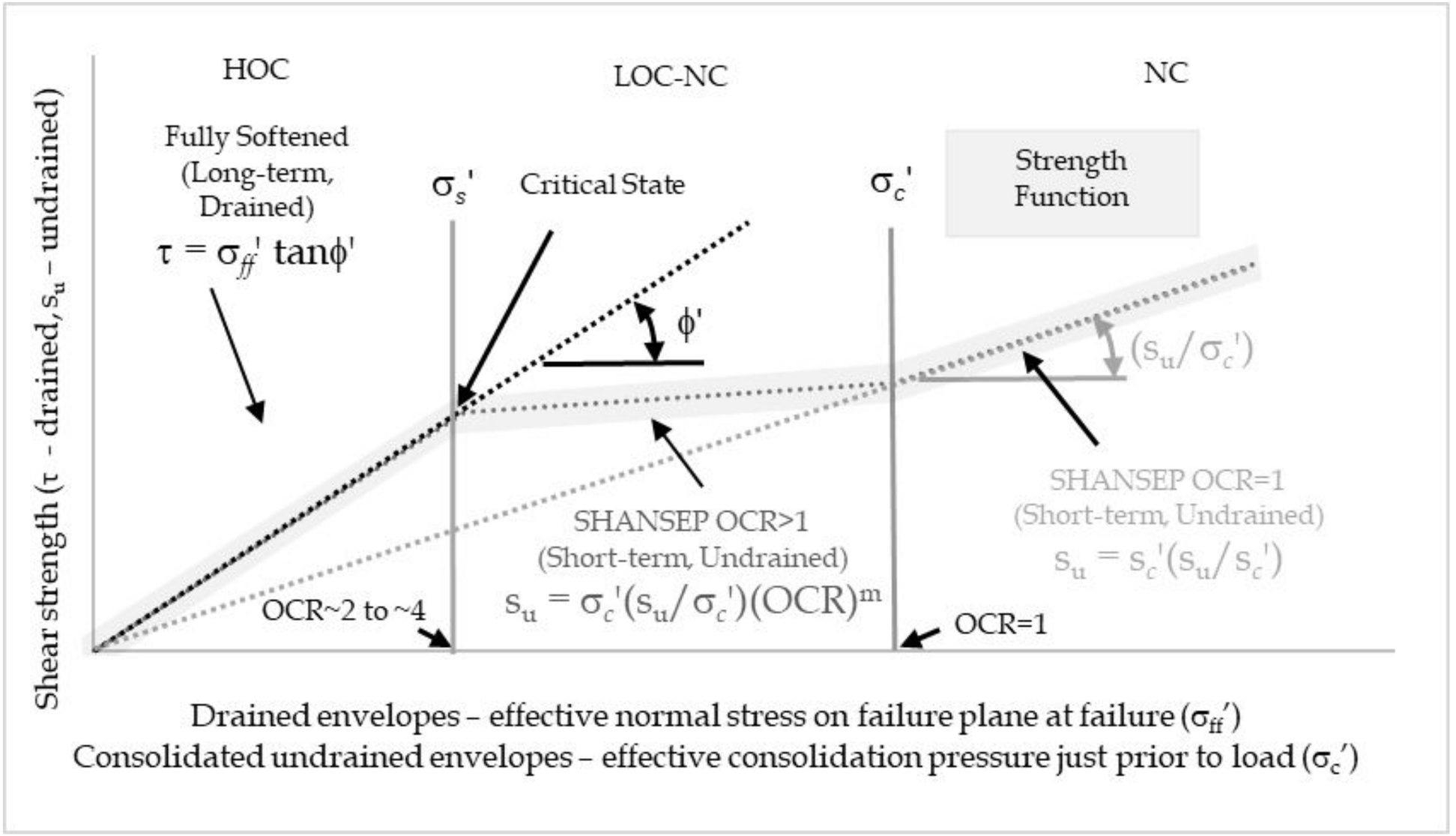
DESIGN QUESTION

Systematic progression from data cloud to a strength function for stability analysis involving fine grained soils

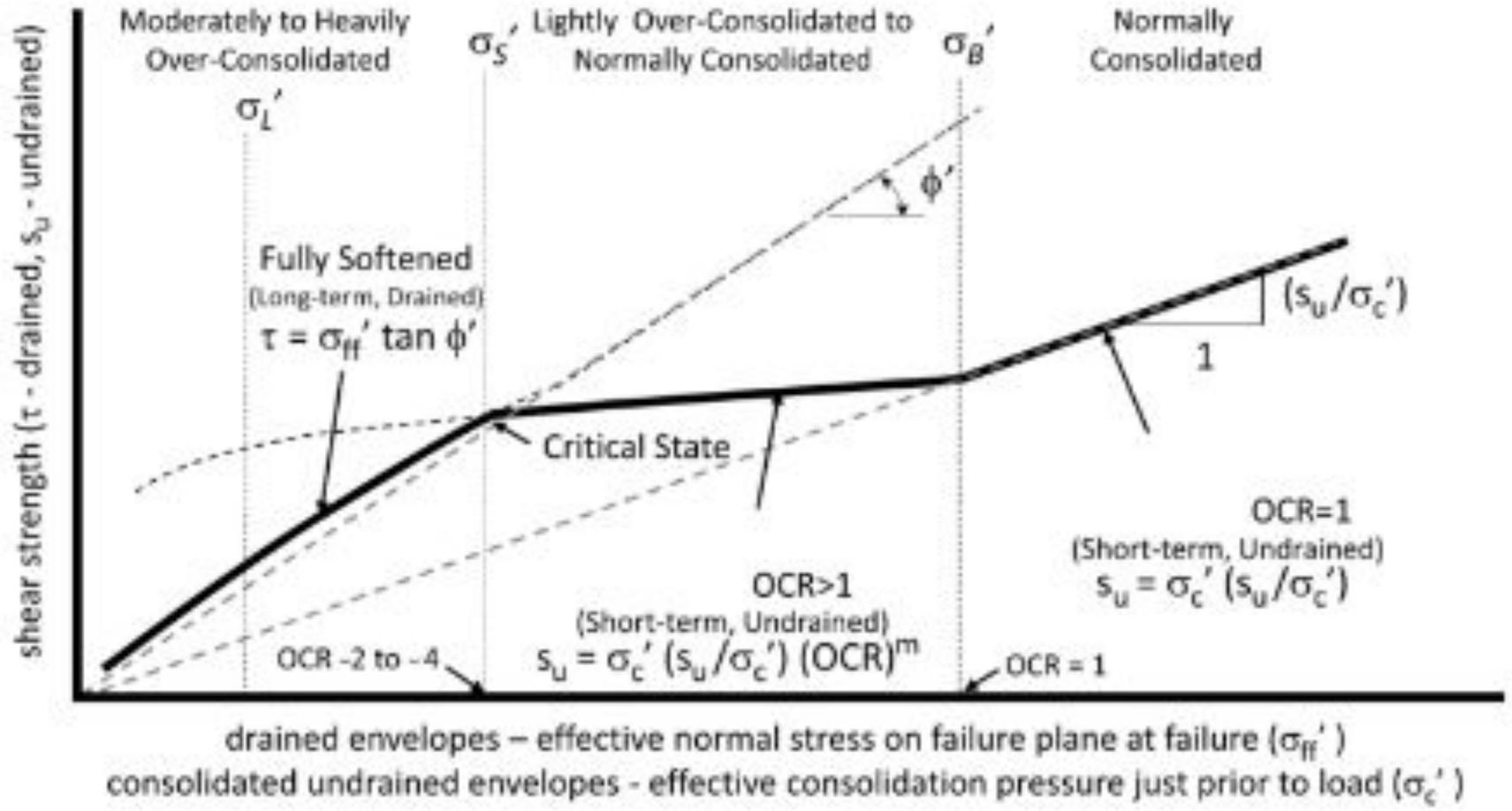




FRAMEWORK

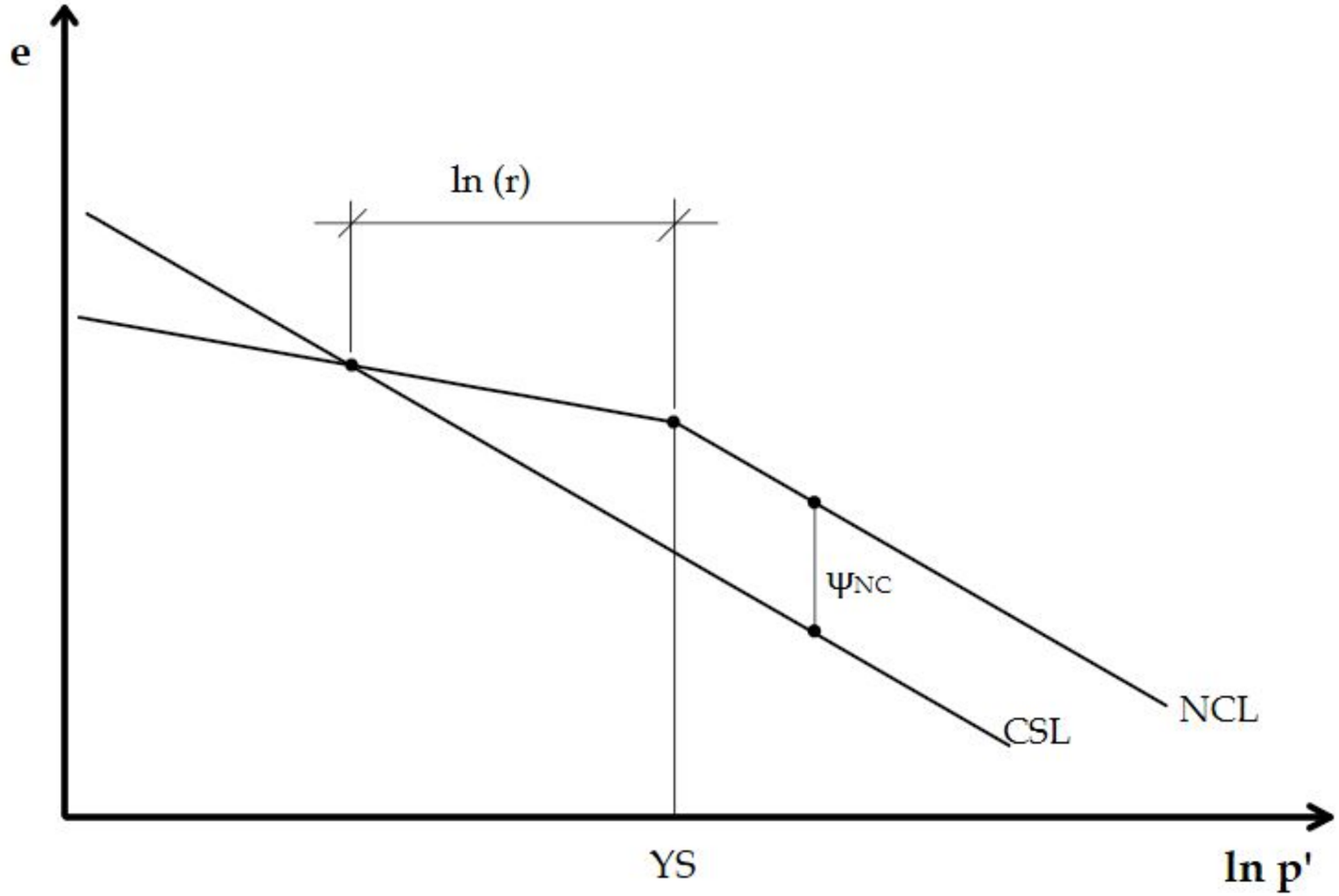

HOC
LOC-NC
NC
Fully Softened
(Long-term,
Drained)
$\tau = \sigma_{ff}' \tan\phi'$
σ_s'
Critical State
σ_c'
Strength
Function
ϕ'
(s_u/σ_c')
SHANSEP OCR=1
(Short-term, Undrained)
$s_u = s_c'(s_u/s_c')$
SHANSEP OCR>1
(Short-term, Undrained)
$s_u = \sigma_c'(s_u/\sigma_c')(OCR)^m$
OCR~2 to ~4
OCR=1
Shear strength (τ - drained, s_u – undrained)
Drained envelopes – effective normal stress on failure plane at failure (σ_{ff}')
Consolidated undrained envelopes – effective consolidation pressure just prior to load (σ_c')

FRAMEWORK

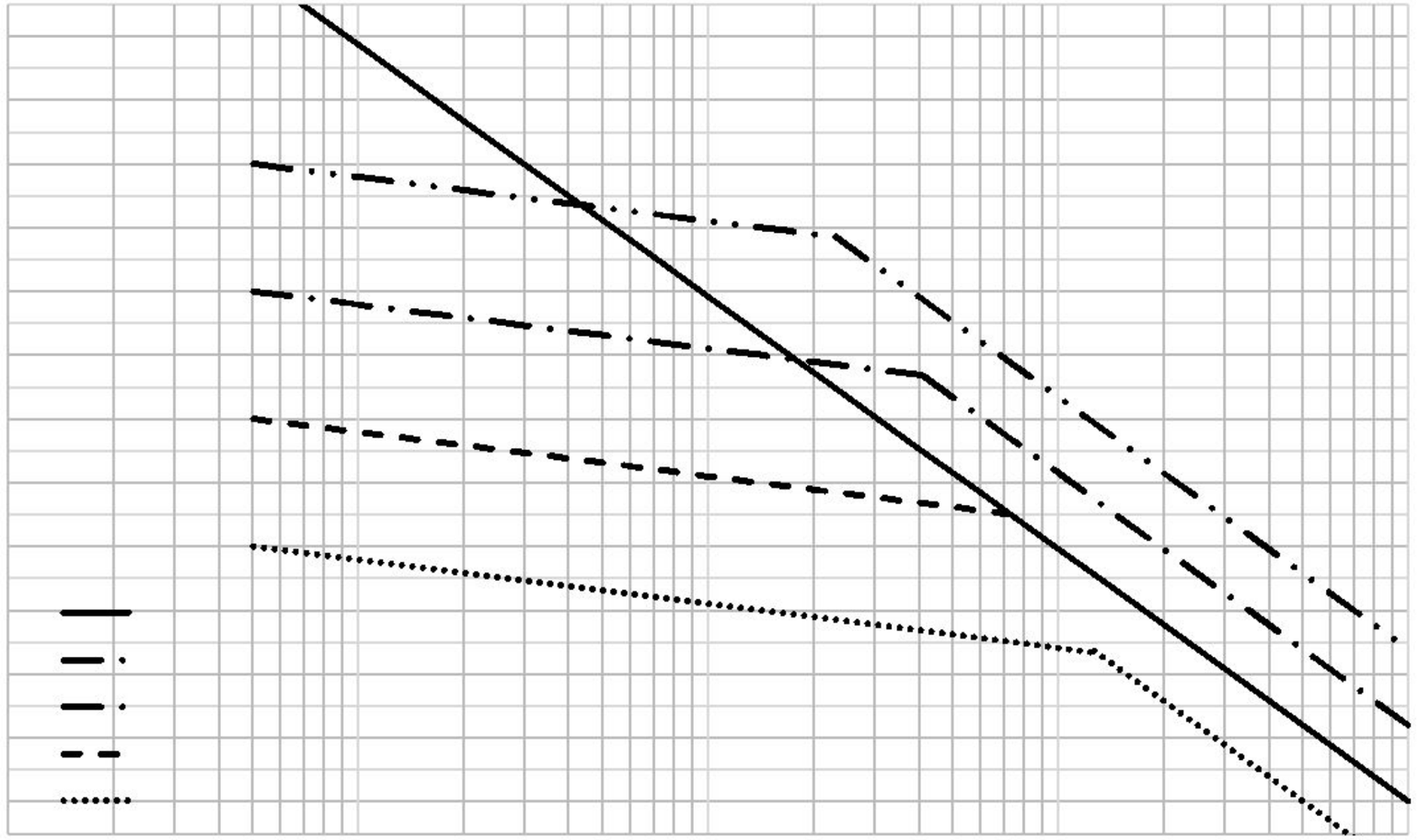

Moderately to Heavily Over-Consolidated
σ_S'
Lightly Over-Consolidated to Normally Consolidated
σ_B'
Normally Consolidated
σ_L'
ϕ'
Fully Softened
(Long-term, Drained)
$\tau = \sigma_{ff}' \tan \phi'$
(s_u/σ_c')
1
Critical State
OCR=1
(Short-term, Undrained)
$s_u = \sigma_c' (s_u/\sigma_c')$
OCR>1
(Short-term, Undrained)
$s_u = \sigma_c' (s_u/\sigma_c') (OCR)^m$
OCR -2 to -4
OCR = 1
shear strength (τ - drained, s_u - undrained)
drained envelopes – effective normal stress on failure plane at failure (σ_{ff}')
consolidated undrained envelopes - effective consolidation pressure just prior to load (σ_c')

KEY: CONSOLIDATION…

State descriptors: YSR and ψ



KEY: …ALONG MANY PATHS



BAUXITE RESIDUE CHARACTERISTICS

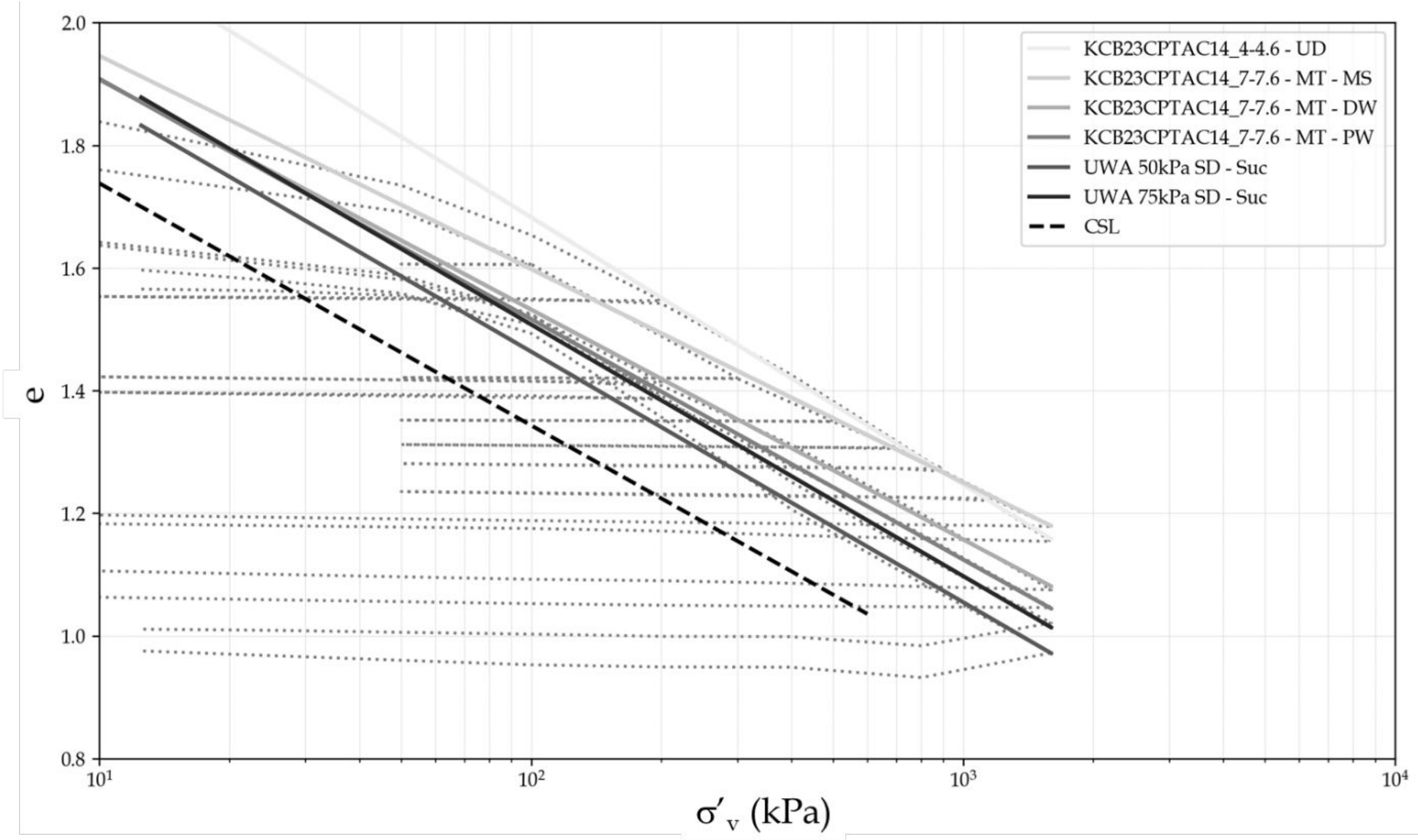
General:

- Poorly graded
- Silt-like to elastic silt; 60–70% silt, 30–40% clay; fines ≈ 94%
- S_G = 2.66–3.58
- LL = 40–79%, PI = 9–21%, PL = 28–38%, SL = 6–13%
- Mineralogy: Fe_2O_3, Al_2O_3, SiO_2

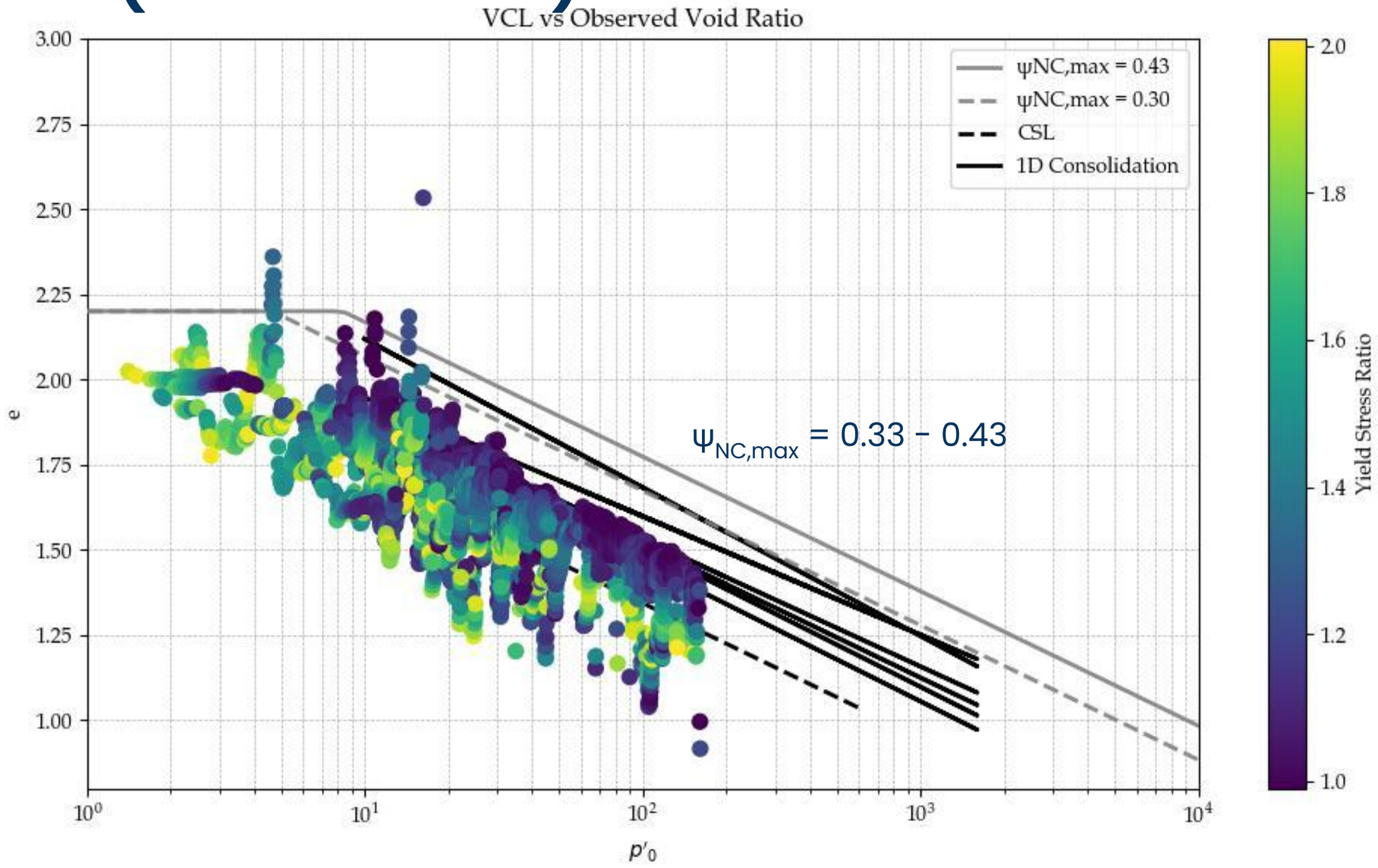
NorSand parameter set (CIU, slurry-deposited):

- CSL: λ_e = 0.17; Γ = 2.13 (at 1 kPa)
- Plasticity: M_{tc} = 1.4; H_0 = 81.7; H_ψ = 150; N = 0.1; χ_{tc} = 5.6
- Elasticity: G_{ref} = 22.9 × 10^3 kPa; n_G = 0.68; v = 0.1

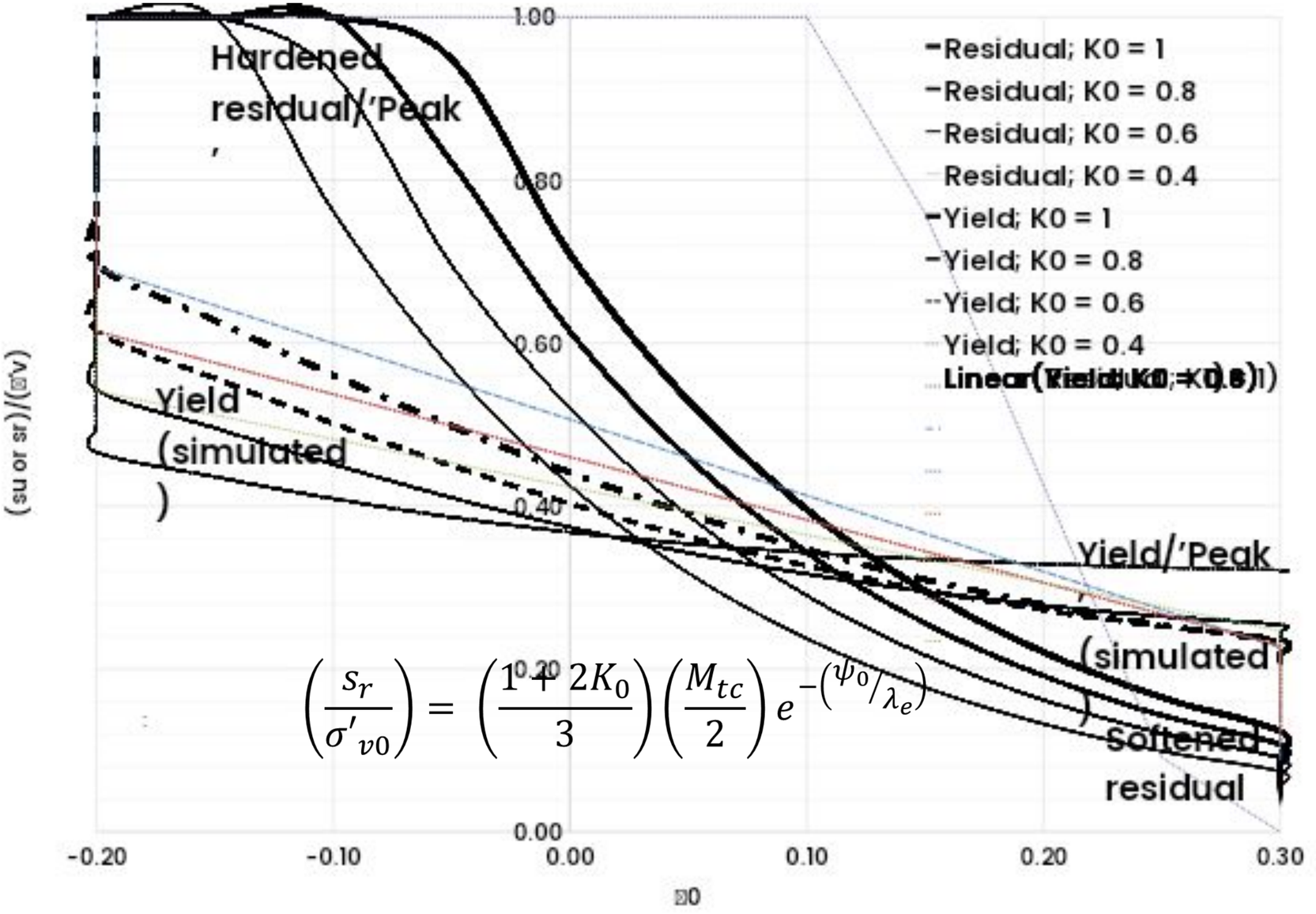
1-D CONSOLIDATION OF BAUXITE RESIDUE



FIELD (FROM CPTu) AND LAB CONSOLIDATION



PREDICTED STRENGTH BEHAVIOUR/ DOMAINS



$\psi_0 = 0$: $s_u/\sigma'_v \approx 0.5$–$0.7$: $\varphi'_c \approx 27° - 35°$ (drained ≈ undrained)

$K_0 \approx 0.6$: $s_u/\sigma'_v \approx 0.35$ (dilative cap on yield)

$K_0 \approx 0.6$: $s_u/\sigma'_v \approx 0.25$ (yield/'peak' to softening)

Softened residual ≈ 0.1

LAB STRENGTH

Yield/'peak' undrained normal distributions

Test type	Preparation	Mean $(s_u/\sigma'_c)^1$ or $(\tau/\sigma'_c)^2$	Standard deviation
MSS	Undisturbed	0.33	0.06
MSS after CSS	Undisturbed & remoulded	0.27	0.05
CIU	Undisturbed	0.33	0.03

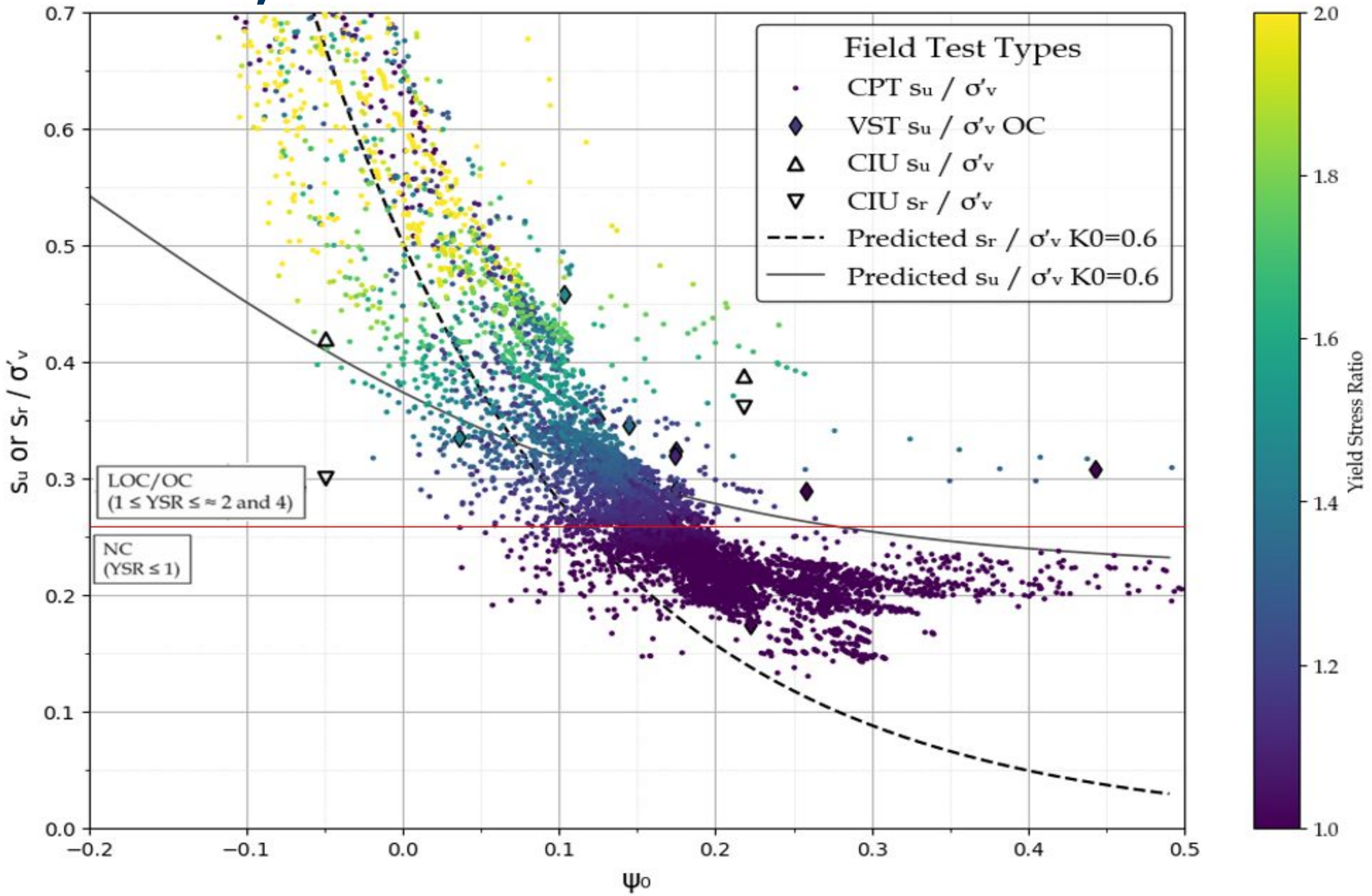
1 – triaxial; 2 – simple shear

Softened drained:

$\varphi'_{cs} \approx 33°$ (predicted 27° - 35°)

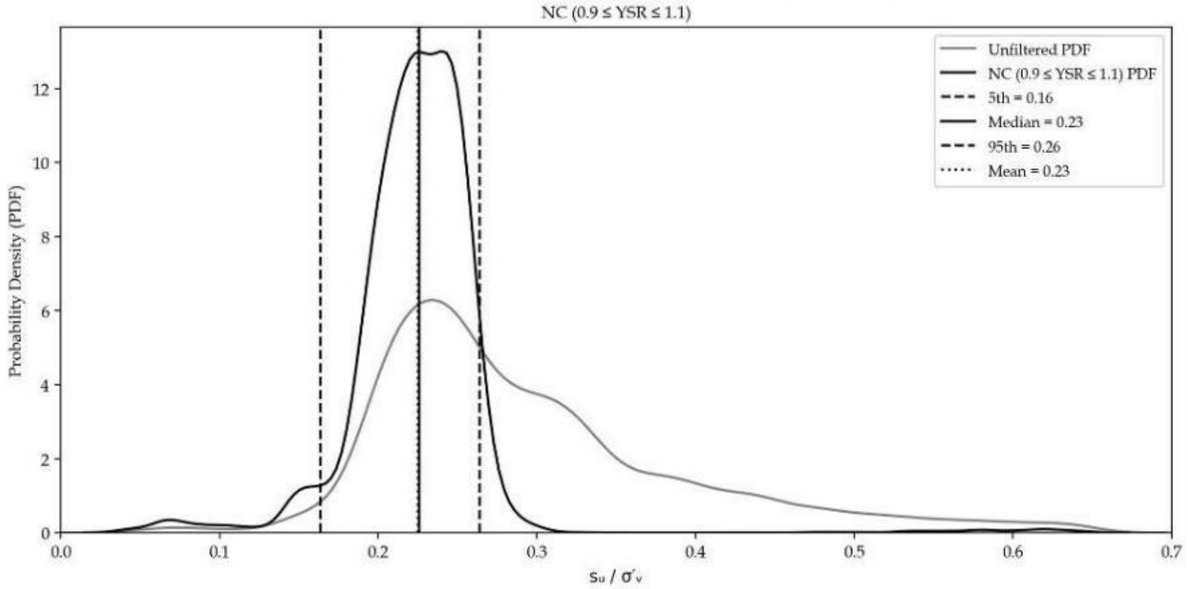
$s_{u,min}$
20 kPa

PREDICTED, LAB & FIELD STRENGTHS



FIELD STRENGTH (NC FILTERED)

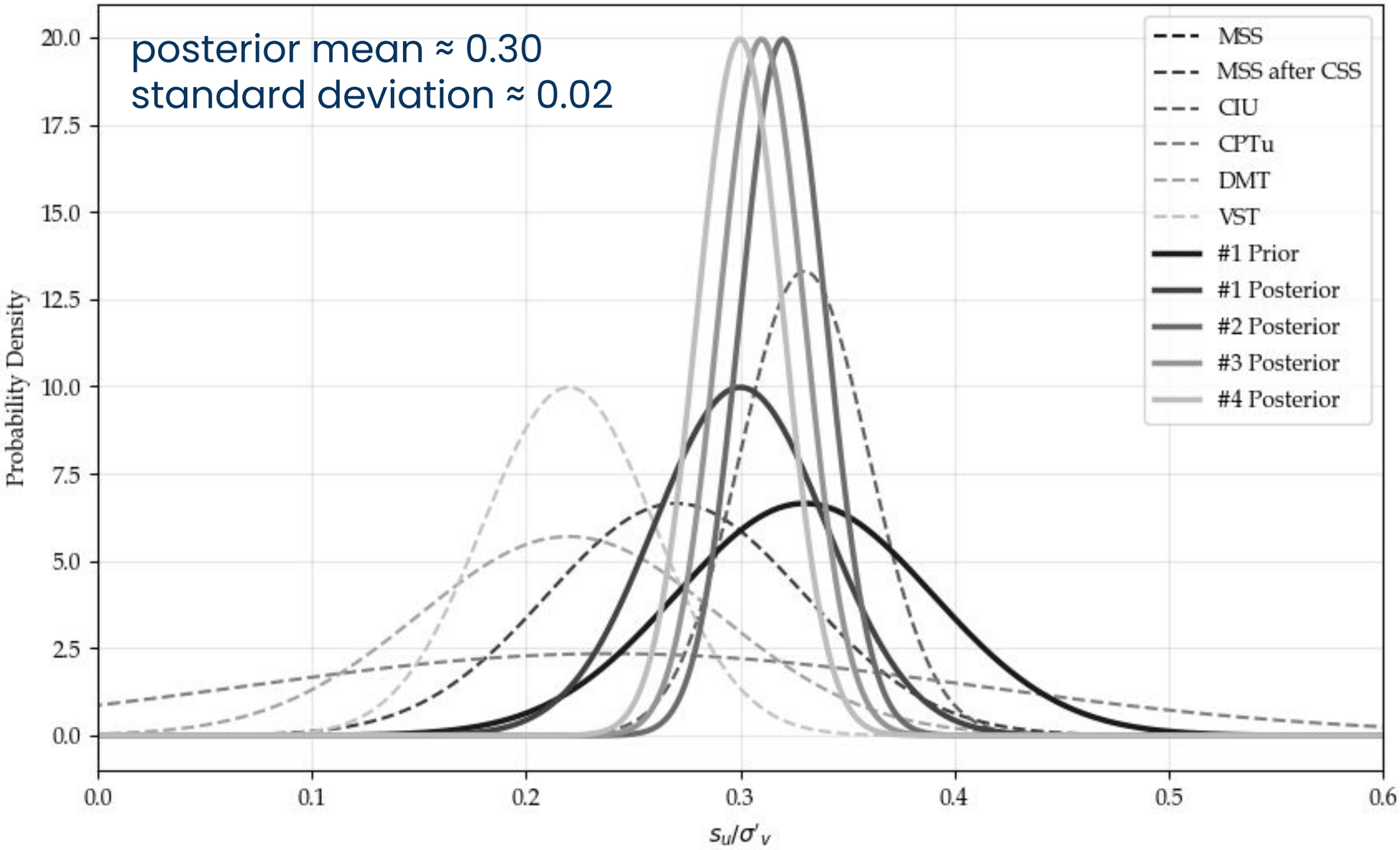
CPTu NC filtered and unfiltered



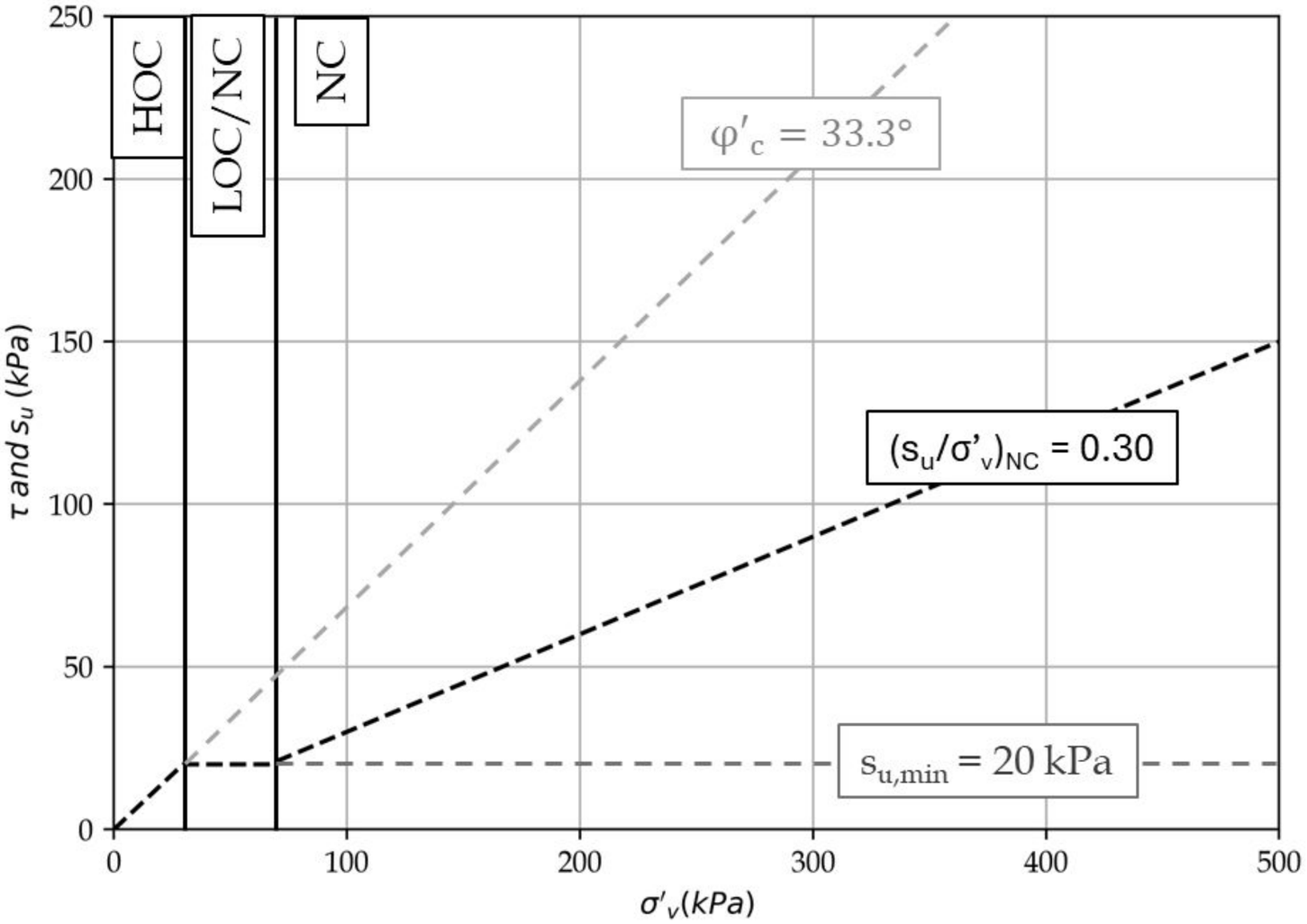
Yield/'peak' undrained normal distributions

Test type	Mean $(s_u/\sigma'_v)_{NC}$ 0.9 < YSR < 1.1	Standard deviation
CPTu-derived (N_{kt}=13)	0.24	0.17
DMT	0.22	0.07
VST	0.22	0.09

LAB AND FIELD DISTRIBUTIONS INTEGRATED



UNDRAINED ‘PEAK’ STRENGTH FUNCTION



CONCLUSION: s_u/σ'_v SELECTION

1. Proceed from understanding consolidation state
2. Define NorSand parameters; predict strength behaviour domains
3. Select lab strength distributions (filter for YSR)
4. Filter field data (for drainage & YSR)
5. Align predicted, lab & field strength behaviours
6. Select field strength distributions
7. Integrate lab and field distributions (e.g. bayesian updating)
8. Define strength function

Klohn Crippen Berger

THANK YOU!

Questions?