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FIFTH INTERNATIONAL ITASCA SYMPOSIUM 2020 VIENNA, AUSTRIA

Prediction of Field Sand Cyclic Resistance in terms of Relative State Parameter Index using Numerical Experiments

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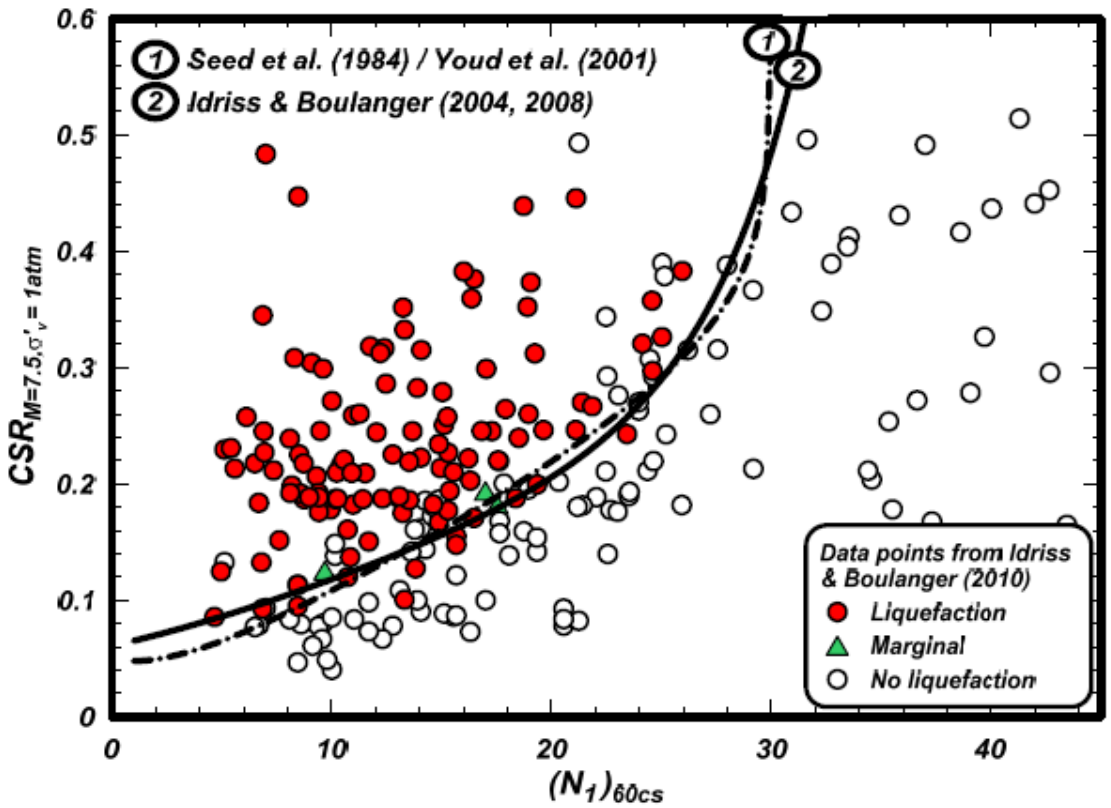
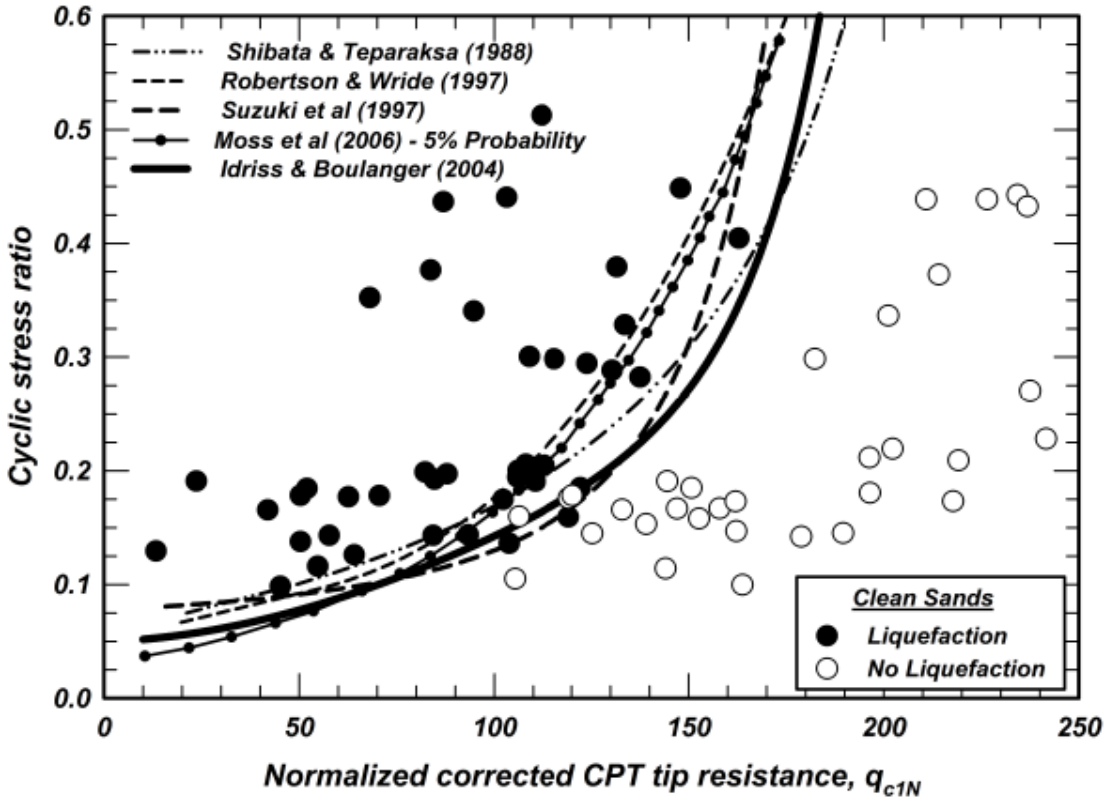
Feb 20th, 2019

Outline

- Why numerical simulations
- Model validations
- Numerical experiments

"Simplified Procedure for Liquefaction Triggering"





(Boulanger & Idriss 2014)

"Simplified Procedure for Liquefaction Triggering"

- **CSR** (Cyclic Stress Ratio): seismic demand:

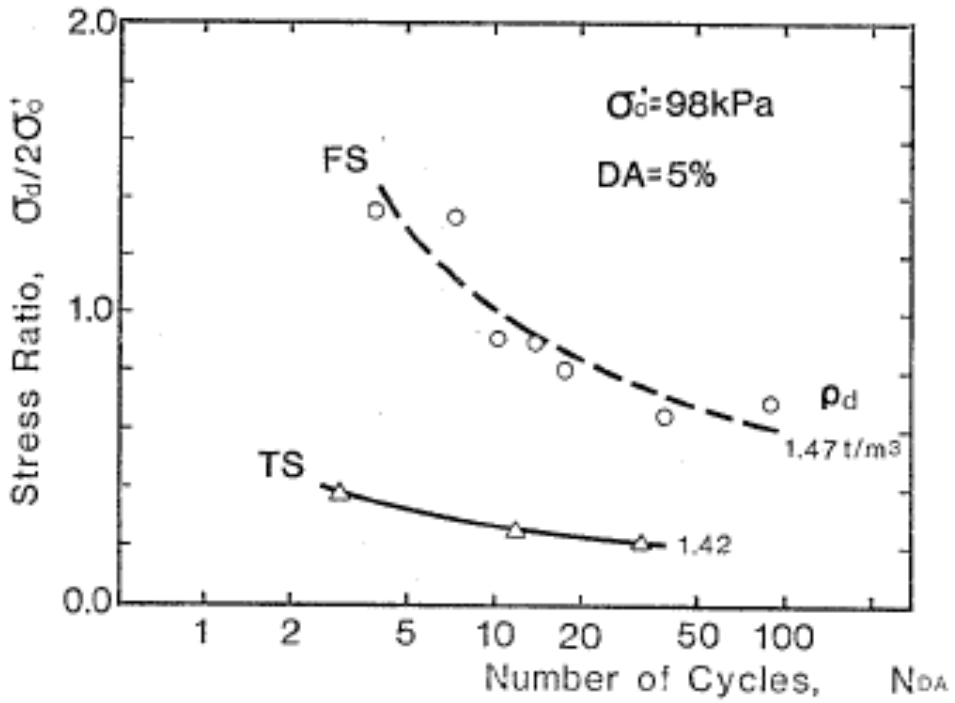
$$CSR = (\tau_{av}/\sigma'_{v0}) = 0.65(a_{max}/g)(\sigma_{v0}/\sigma'_{v0})r_d$$

- **CRR** (Cyclic Resistance Ratio): the capacity of the soil to resist liquefaction:

  CRR from field tests (CPT, SPT, Vs) – state-of-practice

- **FS** = ($CRR_{7.5}$/CSR)×MSF

Lab test data, then which sample?



(After Yoshimi et al 1984)

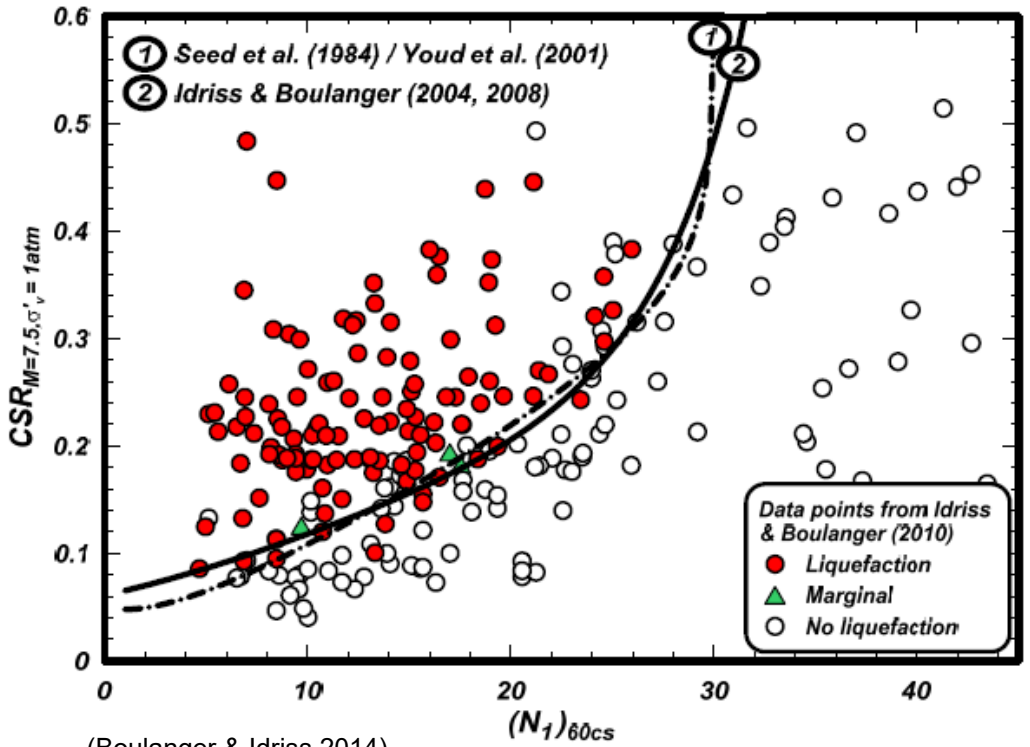
Yoshimi et la (1984) showed that undrained cyclic strength of **triple-tube samples** was ~30%, and **reconstituted samples** was 30~60%, of that of **frozen samples** (supposed close to field conditions).

Contrary to rocks, cyclic strength of sands from lab is **lower** than that in field.

Why **CRR** not from lab experiments?

- "In-situ stress states generally cannot be re-established in the lab, and sampling techniques are too disturbed to yield meaningful results" (Youd et al 2001).
- Specialized sampling technique, i.e. ground freezing, is high-costed and not practical.
- So it should not be assumed that lab-based parameters are directly applicable to in-situ soil conditions.

How to represent the field sand:



(Boulanger & Idriss 2014)

The CRR curve based on the “simplified procedure” does not correspond to a **specific** field sand but is **statistically** derived from many field cases.

It is possible to simulate numerically a **SCRF Sand** (Standard Cyclic Resistance Field sand) that liquefies exactly in 15 uniform cycles under DSS (direct simple shear) loading with an initial overburden stress of 100 kPa.

Practice-orientated constitutive model:

- Models heavily relying on high-quality lab-tests (or apparent discrepancies to field-based empirical formula) are not practical.
- In recent years, practice-oriented constitutive models consistent with this simplified procedure are increasingly appealing to engineers.
- General 3D: P2PSand (available from FLAC3D v7).

How to represent the field sand:

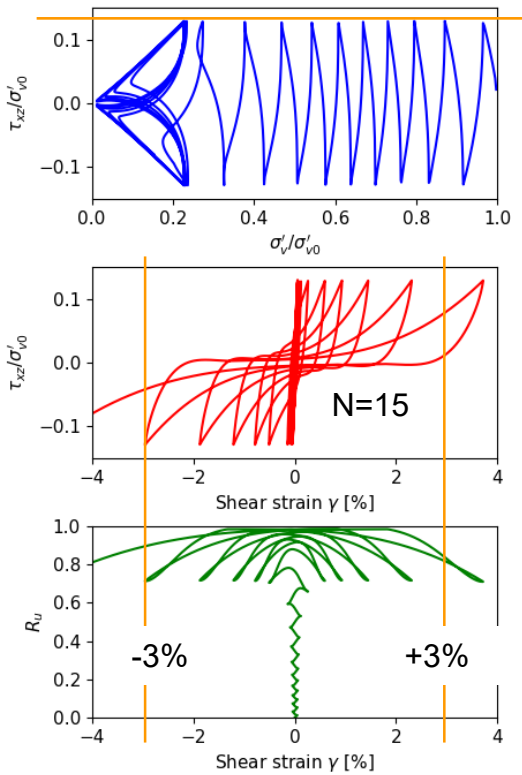
In P2PSand Model, the default parameters are calibrated for the **SCRF Sand**) :

- Undrained DSS single-zone simulations
- Initial $\sigma'_{v0} = 100$ kPa, $K_0 = 0.5$ and no static shear stress.
- 15 cycles are required to reach liquefaction when CSR is equal to a selected standard CRR, see e.g., Youd et al. (2001).
- Liquefaction occurs when the peak shear strain first reaches a 3% amplitude.

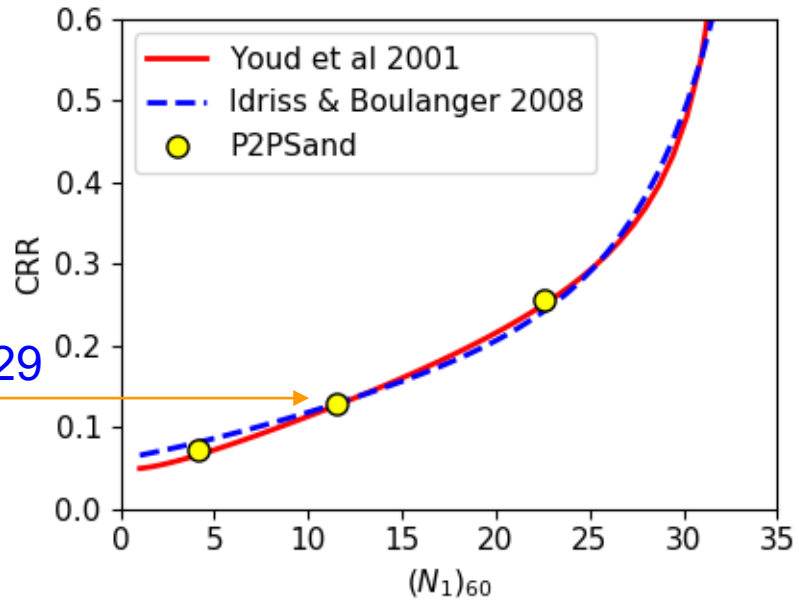
"Standard" single-zone numerical example

- An example in FLAC3D v7 manual: Dynamic\CyclicUndrainedDirectSimpleShear

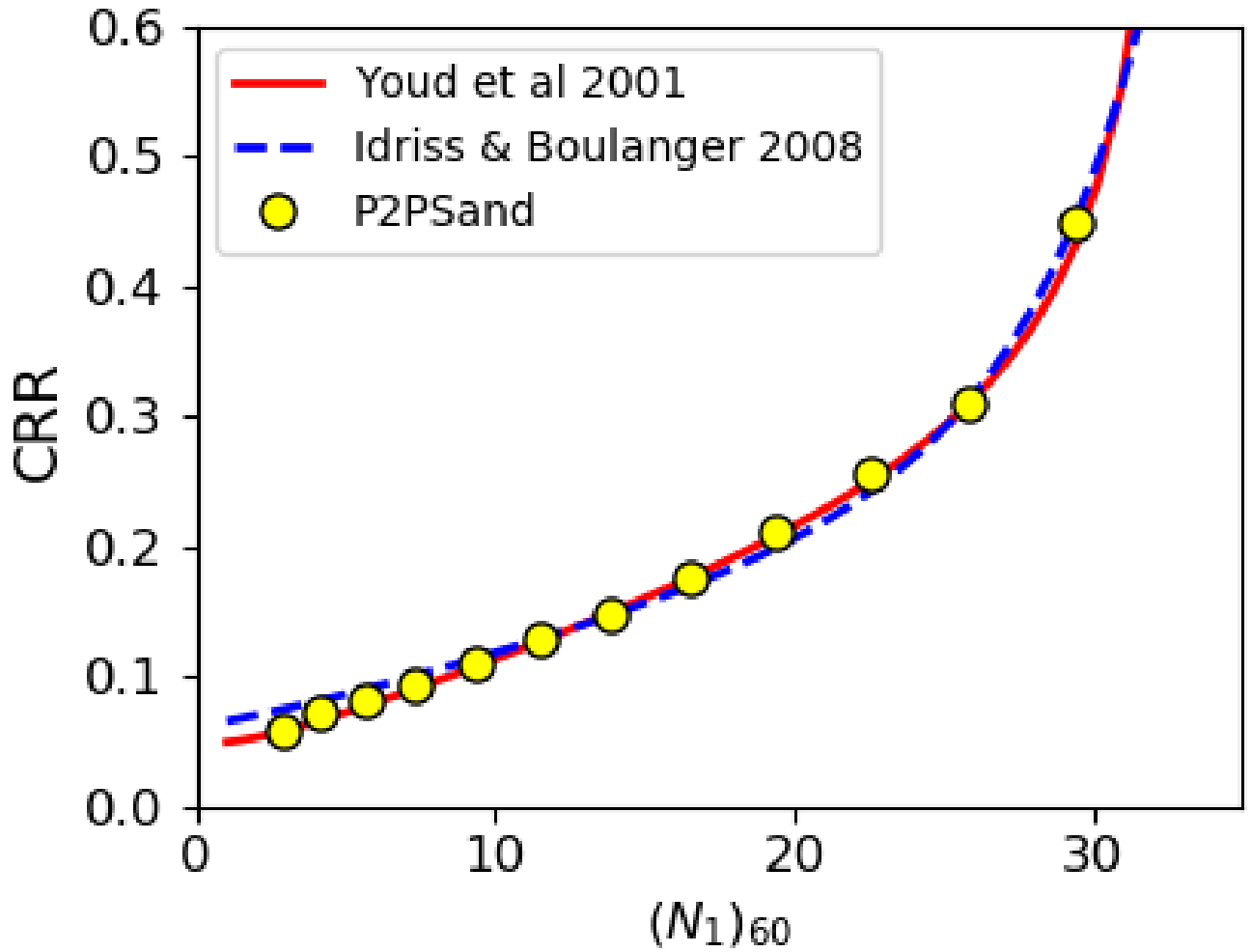
CSR=0.129



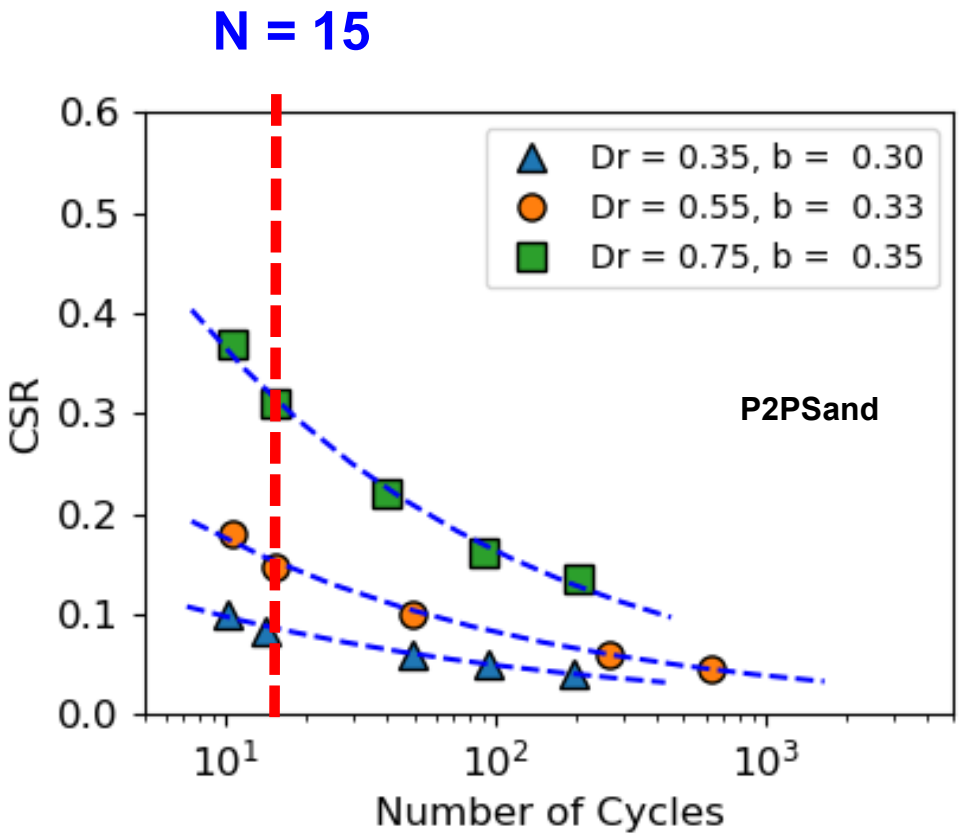
CSR=0.129



CRR

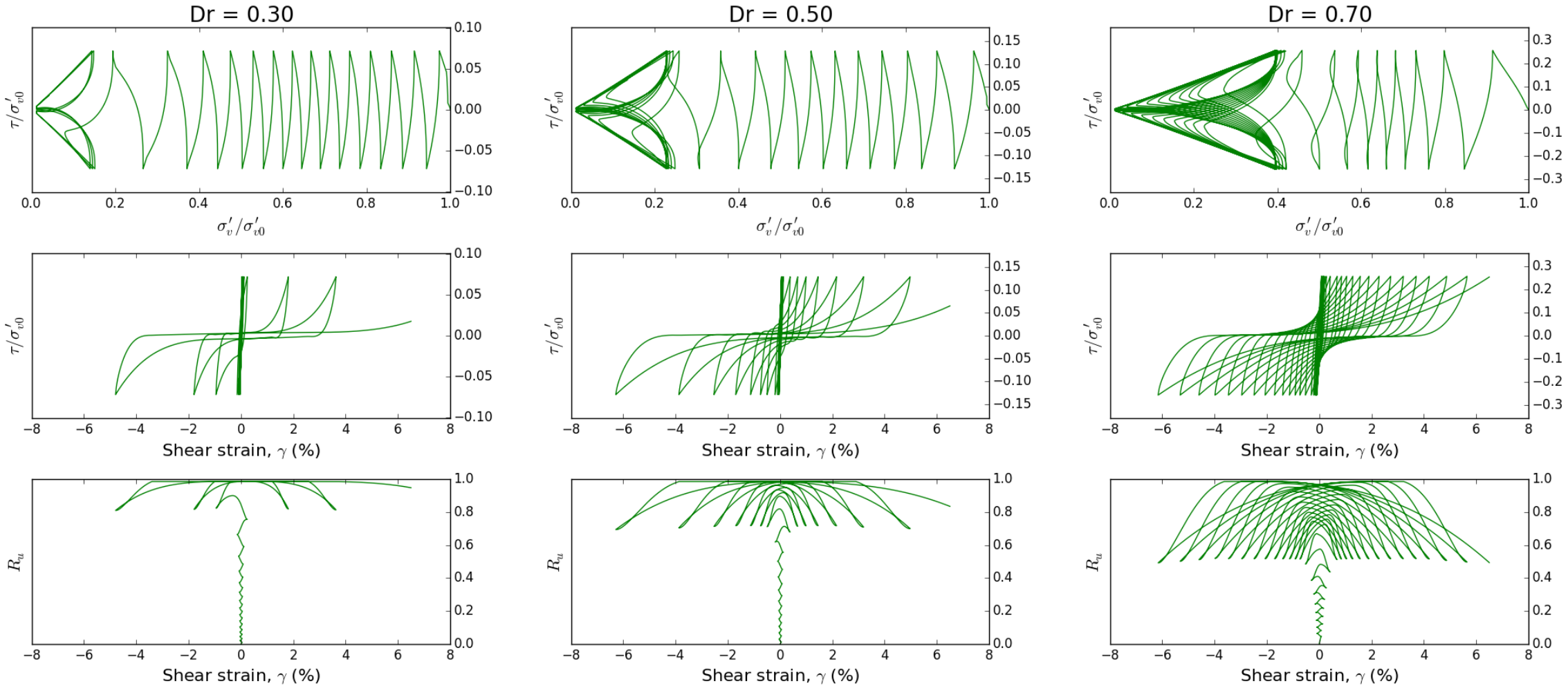

Youd et al 2001
Idriss & Boulanger 2008
P2PSand
CRR
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
10
20
30
$(N_1)_{60}$

CSR-N (Number of Cycles)



If too steep, it over-estimates CSR for M > 7.5 (not conservative) & under-estimates CSR for M < 7.5 (overly-conservative).

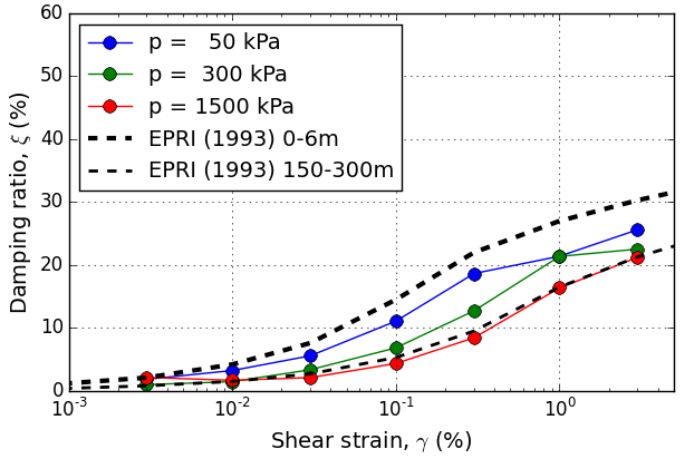
DSS cyclic simulation

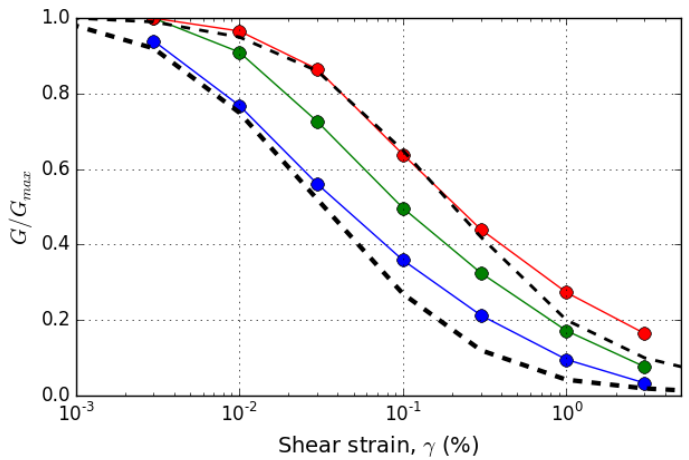


G/G_{max} & damping

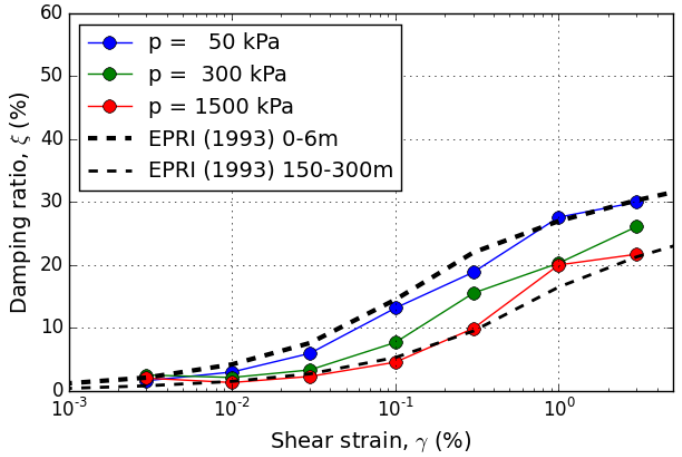
constant-p triaxial test simulation

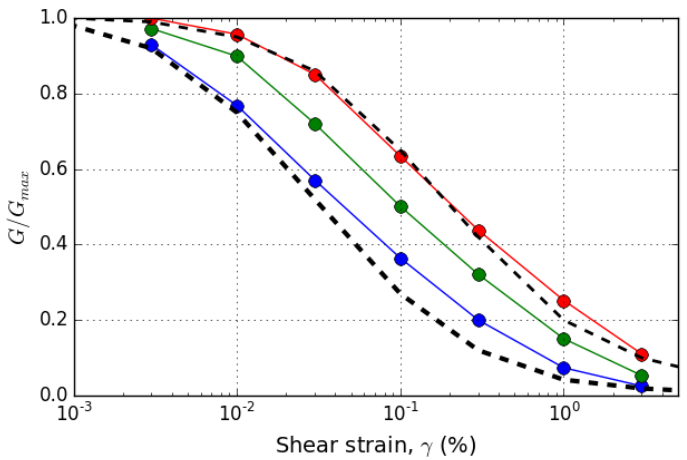
Dr = 0.35



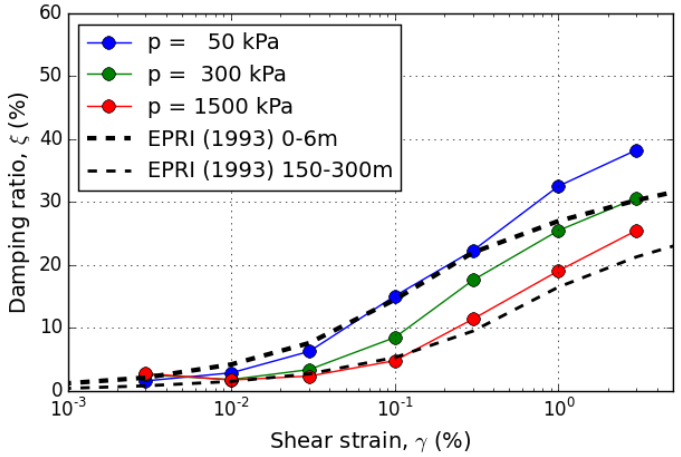


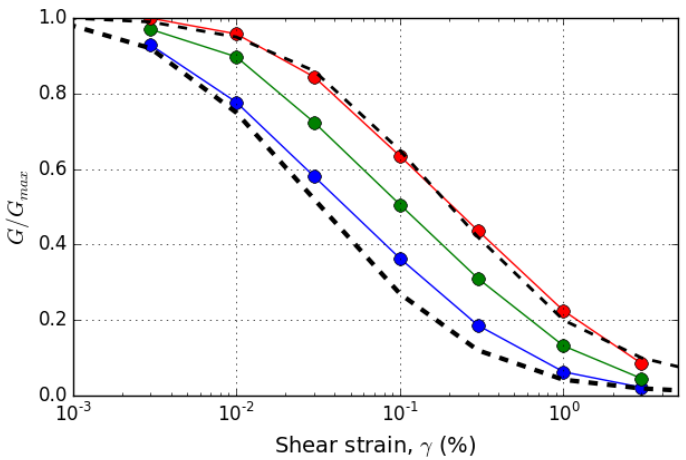
Dr = 0.55



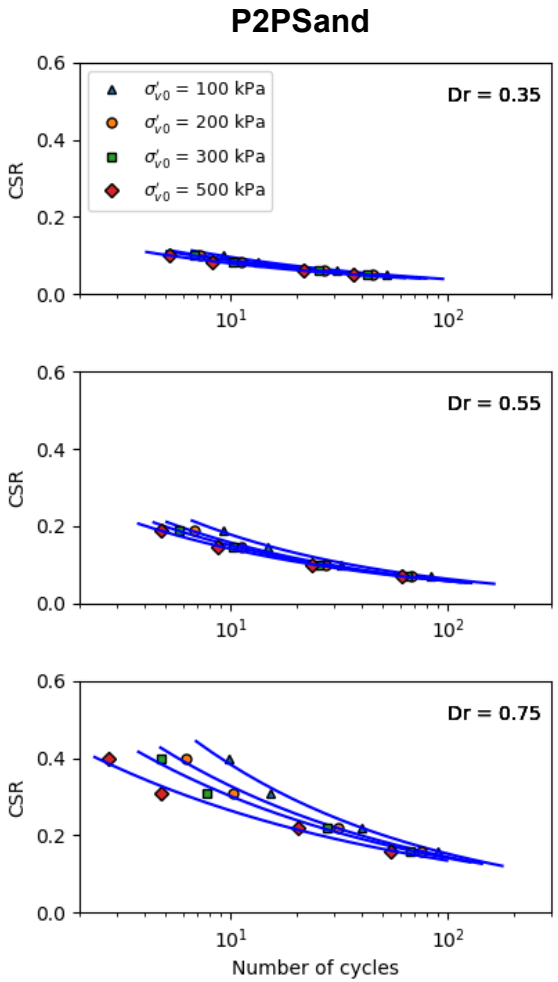


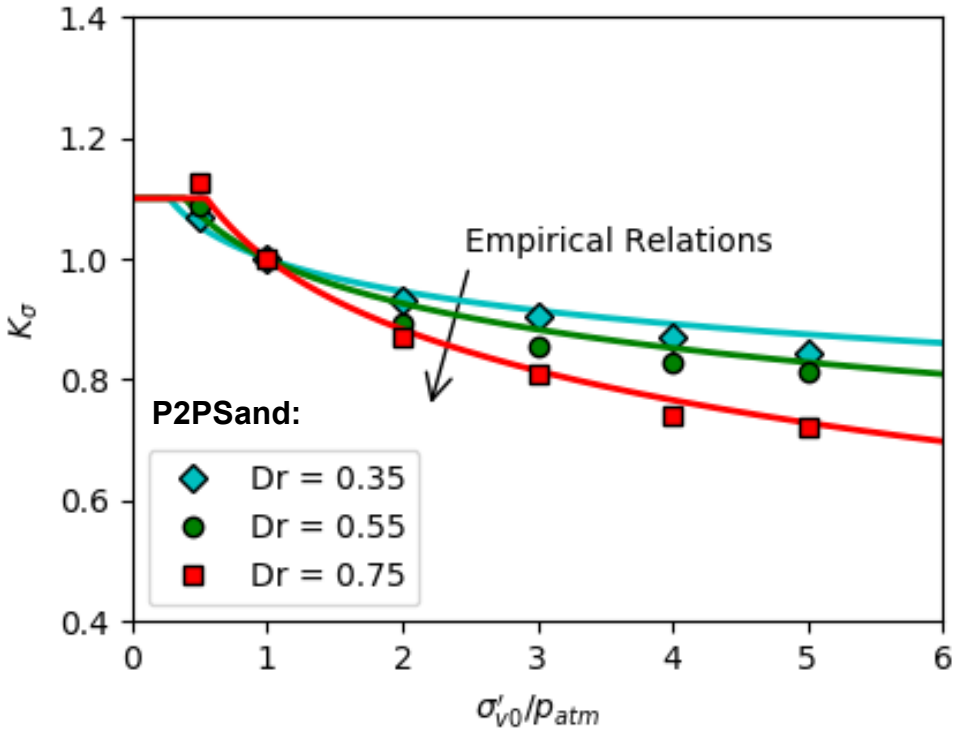
Dr = 0.75





Kσ effect


P2PSand
Dr = 0.35
Dr = 0.55
Dr = 0.75
σ'_{v0} = 100 kPa
σ'_{v0} = 200 kPa
σ'_{v0} = 300 kPa
σ'_{v0} = 500 kPa
CSR
Number of cycles


Empirical Relations
P2PSand:
Dr = 0.35
Dr = 0.55
Dr = 0.75
K_σ
σ'_{v0}/p_{atm}

SCRF Sand **statistically** stands for field sand:

Calibrated parameters are good for:

- CRR
- CSR vs N
- General Cyclic Curves
- G/Gmax & Damping vs Shear Strain
- Kσ Effect

Can we predict something else meaningful for SCRF Sand purely by numerical experiments?

120 numerical DSS experiments:

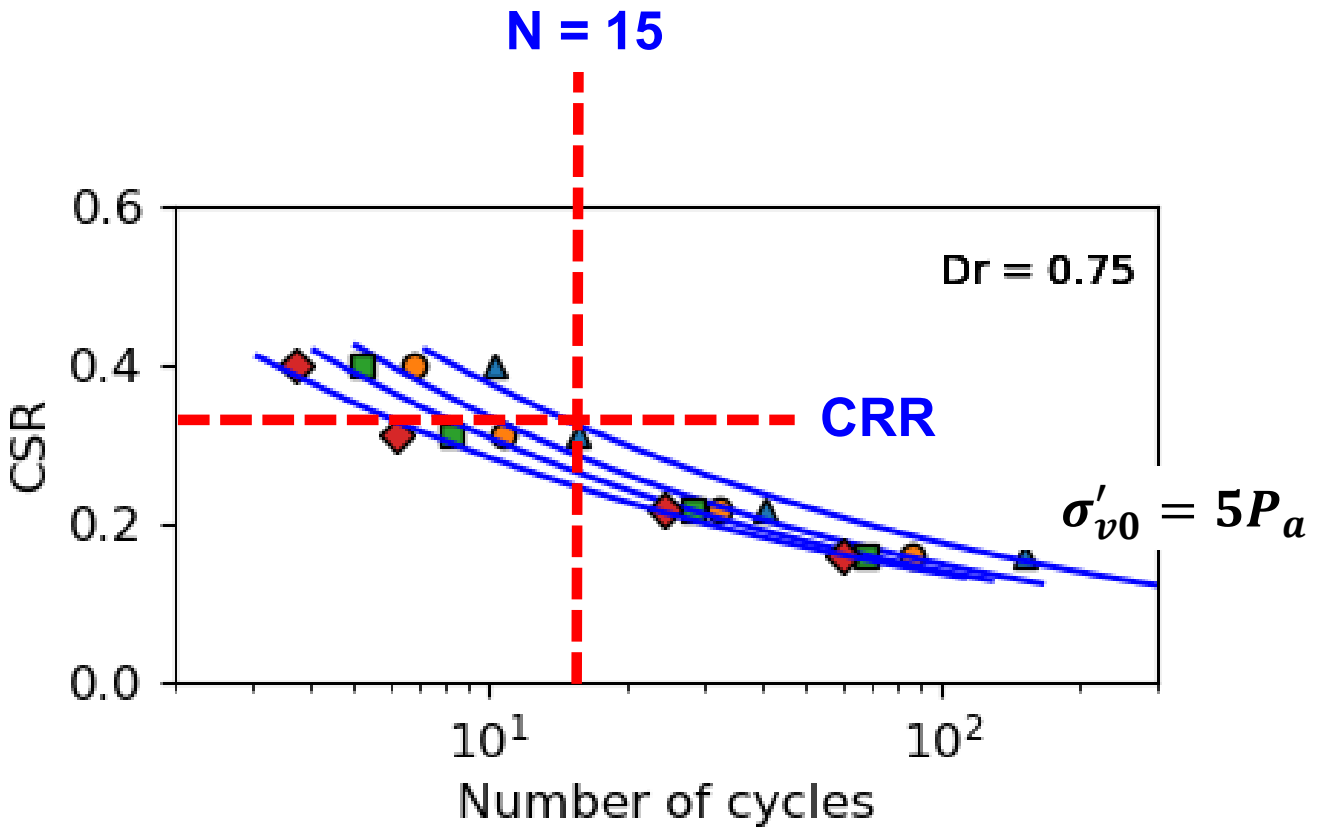
```
csrdict  = {0.75 : [0.400, 0.311, 0.220, 0.160],
            0.65 : [0.280, 0.212, 0.160, 0.110],
            0.55 : [0.190, 0.147, 0.100, 0.070],
            0.45 : [0.130, 0.109, 0.080, 0.060],
            0.35 : [0.100, 0.084, 0.060, 0.050]}

pv0list  = [50, 100, 200, 300, 400, 500]

for dr0, csrlist in sorted(csrdict.items()) :
    for pv0 in pv0list :
        for csr in csrlist :
            it.command("model new")
            it.fish.set('dr0', dr0)
            it.fish.set('csr', csr)
            it.fish.set('Sv0', pv0)
            it.command("call 'dss_cyc_ud_n.f3dat' ")
```

- **5** relative densities: Dr = 0.35, 0.45, 0.55, 0.65, 0.75
- **6** initial over-burden stresses: σ'_{v0}/P_{atm} = 0.5, 1, 2, 3, 4 and 5
- **4** CSRs

Python scripts in FLAC3D do the job easily!

Post-processing numerical data :

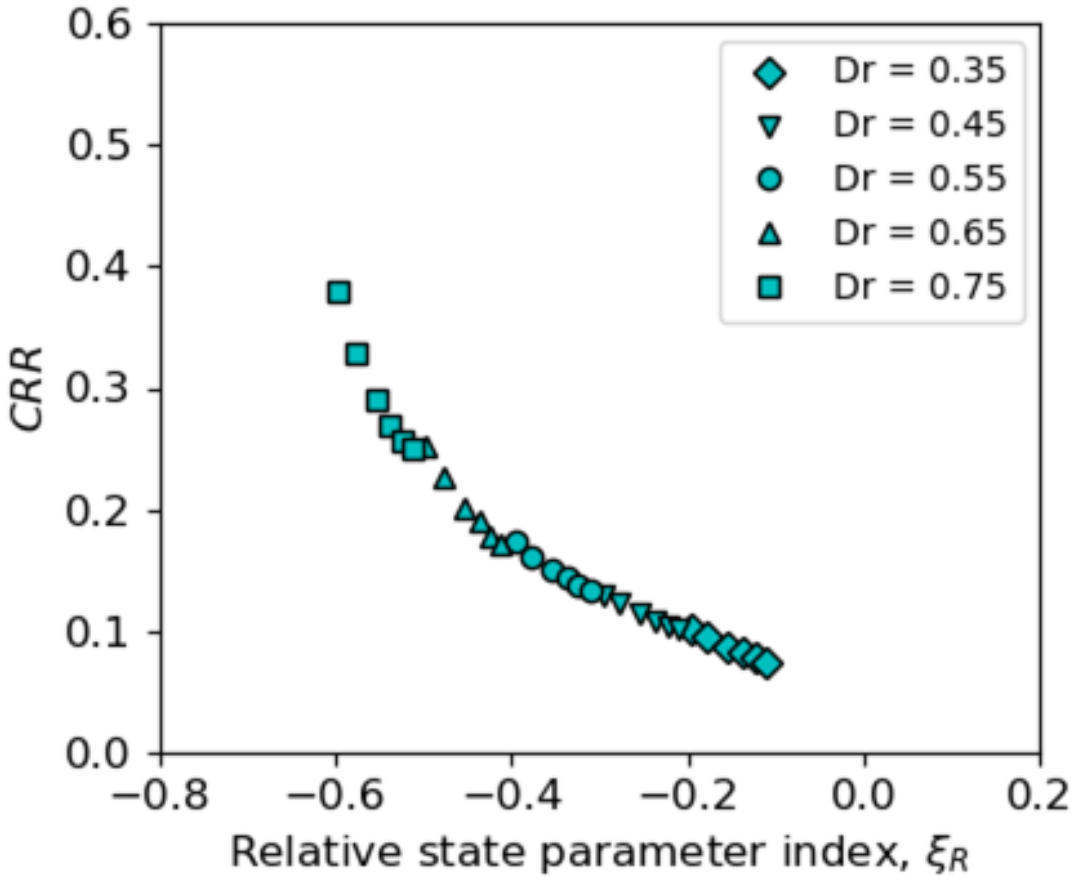
5×6 CRR vs (Dr, σ'_{v0})



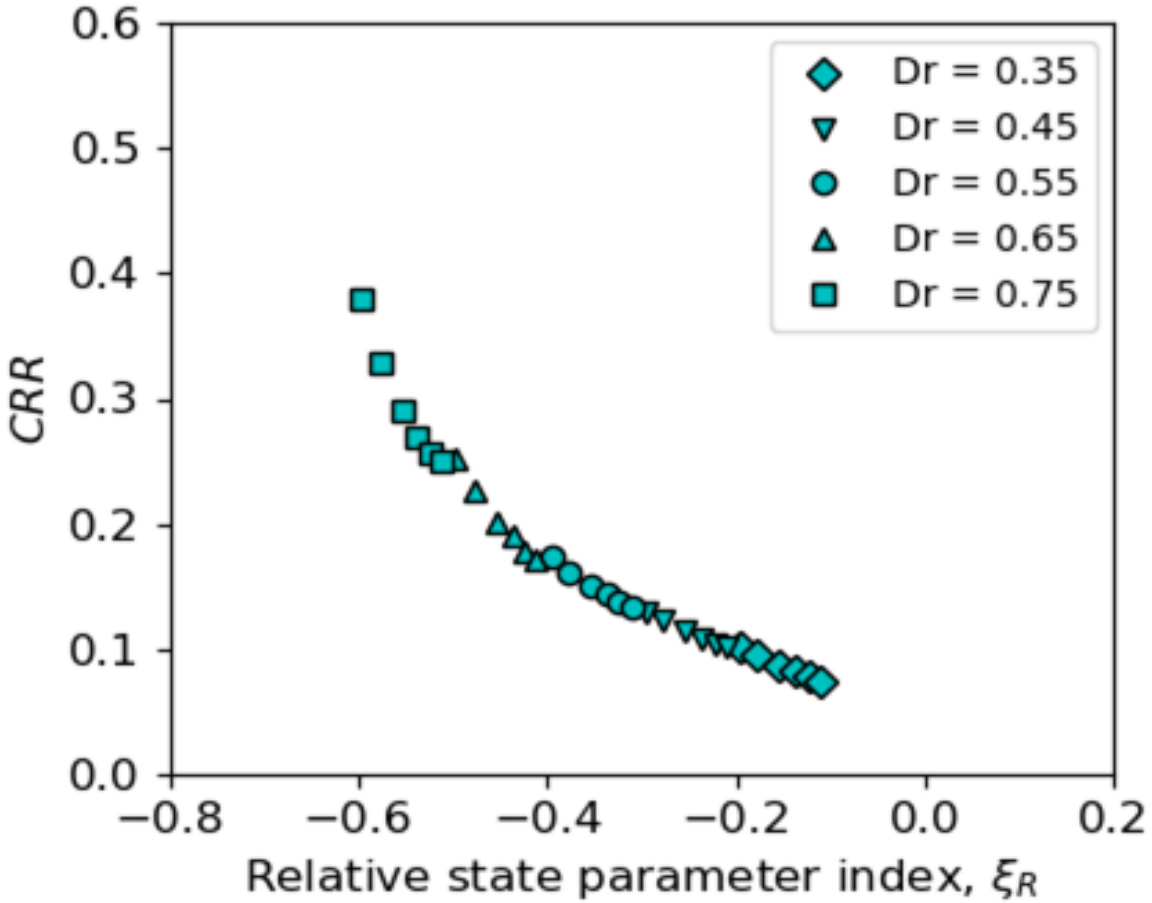
Post-processing numerical data :

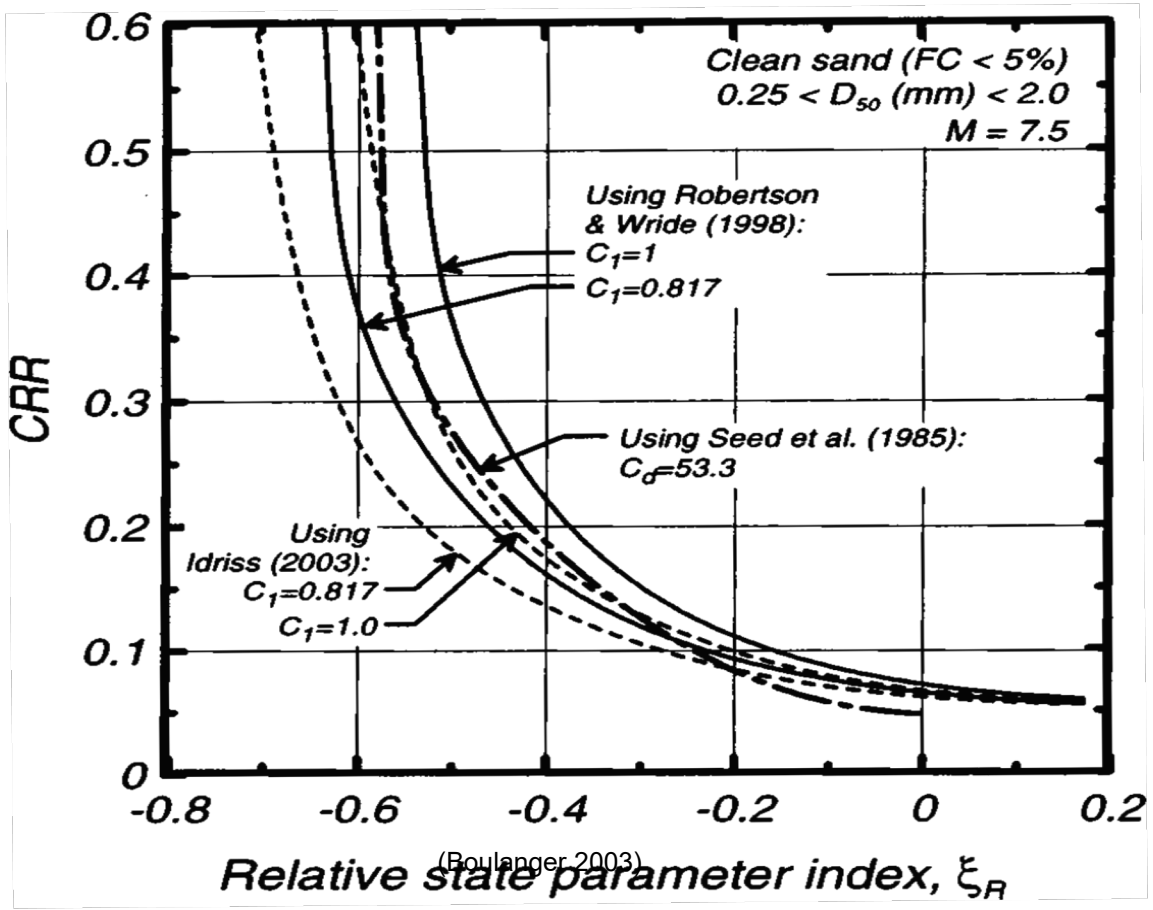
- Can we use one Index to represent (Dr. σ'_{v0}) to correlate CRR?
- Relative State Parameter Index:

$$\xi_R = D_{rc} - D_r$$



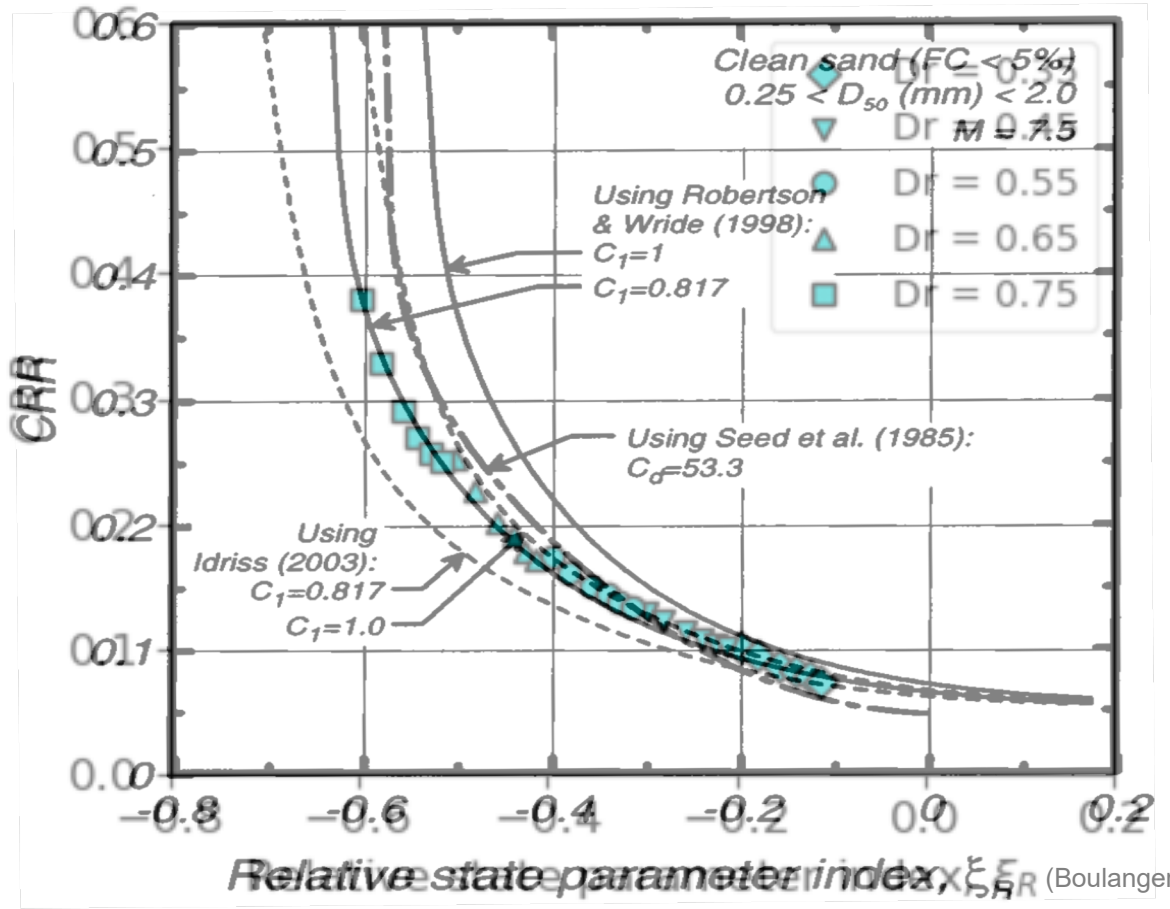
Compare with field data





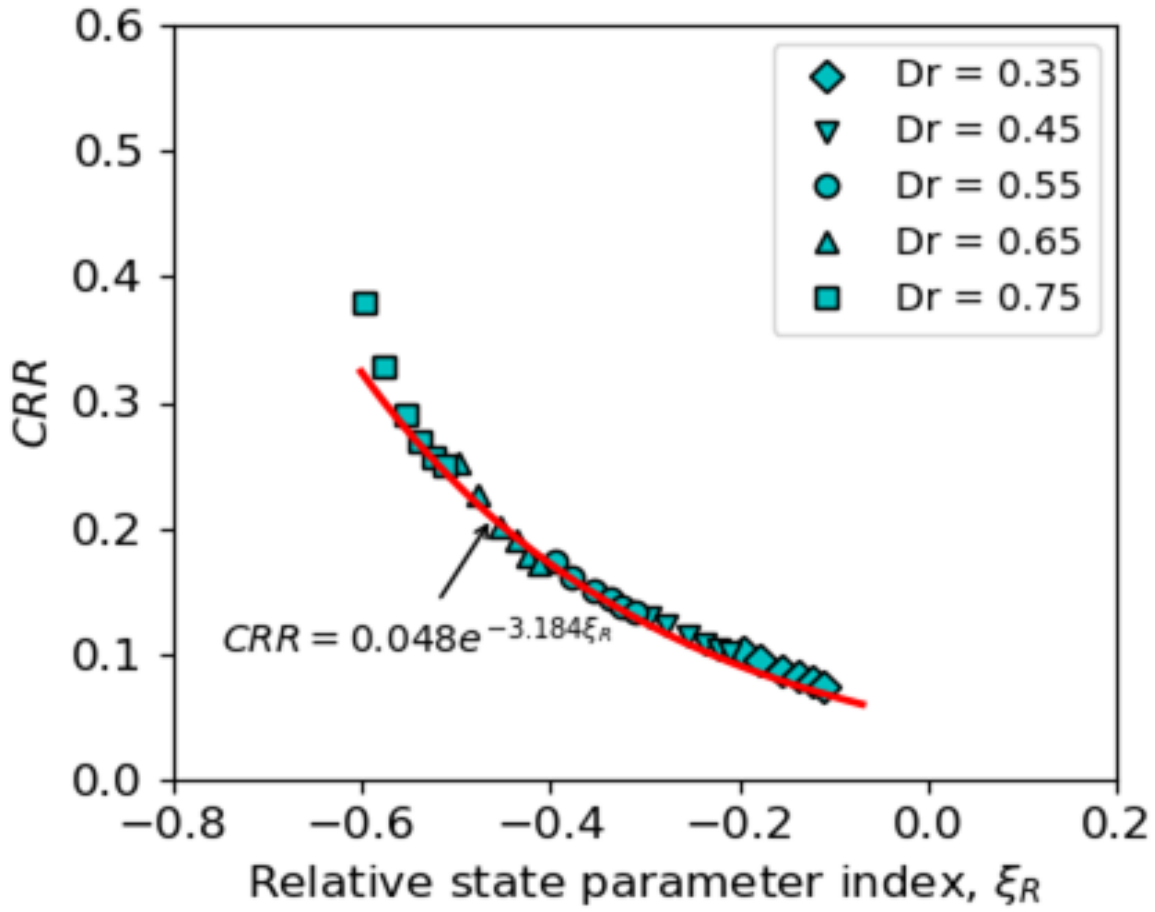
(Boulanger 2003)

Compare with field data, II



(Boulanger 2003)

Empirical relation purely derived from numerical experiments



- A simple power relation
- Kσ effect intrinsically included

Summaries

- Default properties of P2PSand model are compatible to SCRF Sand.
- Purely numerical cyclic DSS experiments using P2PSand model with various combinations of initial (Dr, σ'_{v0}) are performed.
- Numerical experiment results are validated by the results derived from field conditions.
- Numerical results suggest a simple power correlation between CRR vs ξ_R (relative state parameter index) for clean field sands.

Thank You!