Exploring liquefaction behavior of sand with discrete element simulations

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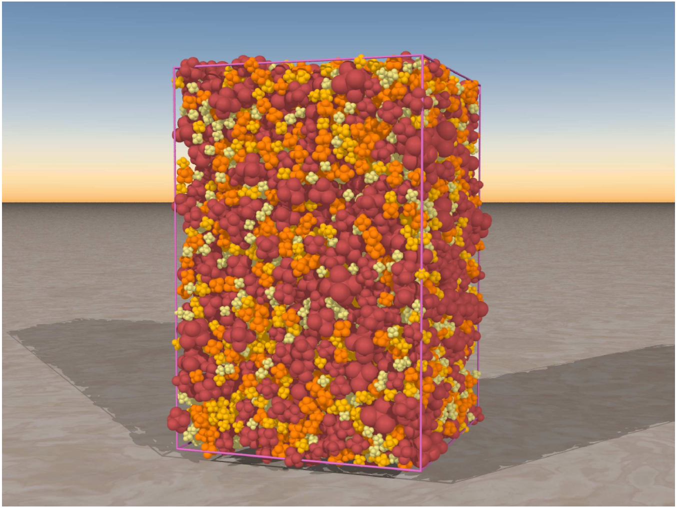
DEM assembly of 6400 "bumpy" particles



DEM Assembly

- Targeted material: Nevada Sand
- $D_{50} = 0.165\text{mm}$, $C_u = 2.2$
- 6400 particles: lumpy sphere conglomerates
- Void ratio, $e = 0.641$. Relative density, $D_r = 50\% - 60\%$??

Outline

- Three loading cases:

Case I	Uniform amplitude cyclic shearing
Case II	Sequences of small and large shear pulses
Case III	Erratic, seismic shearing

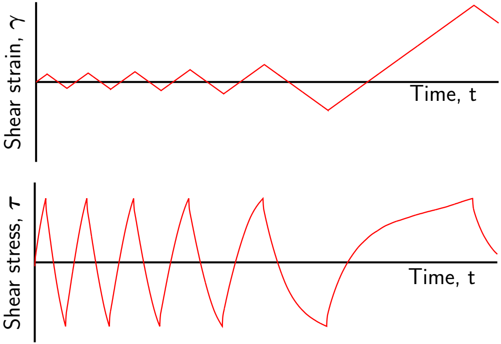
- Suitable “Severity Measure” for predicting initial liquefaction

General loading conditions

- Isotropic consolidation, 80 kPa
- Uni-directional cyclic simple shear
- Undrained conditions: $\varepsilon_{11} = 0$, $\varepsilon_{22} = 0$, $\varepsilon_{33} = 0$,
- Effective stresses inferred from the contact forces

Case I: Uniform cyclic shearing

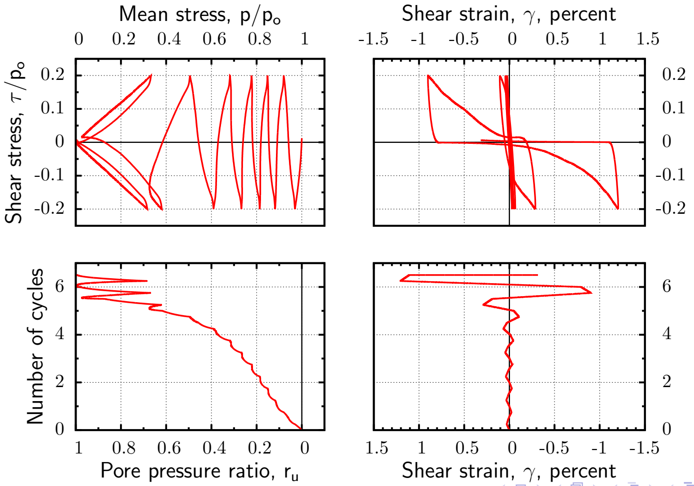
Uniform shearing amplitude:



Control strain rate $\dot{\gamma}$ in a sawtooth pattern until the targeted shear stress τ is attained.

Case I: Uniform cyclic shearing

Conditions: $\tau = \pm 16$ kPa, $p_o = 80$ kPa



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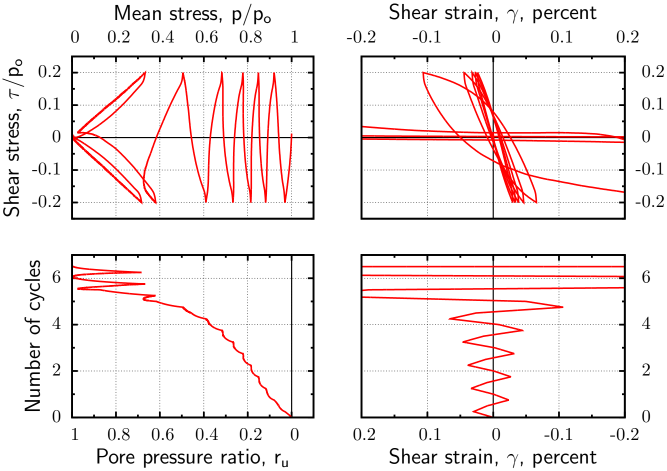
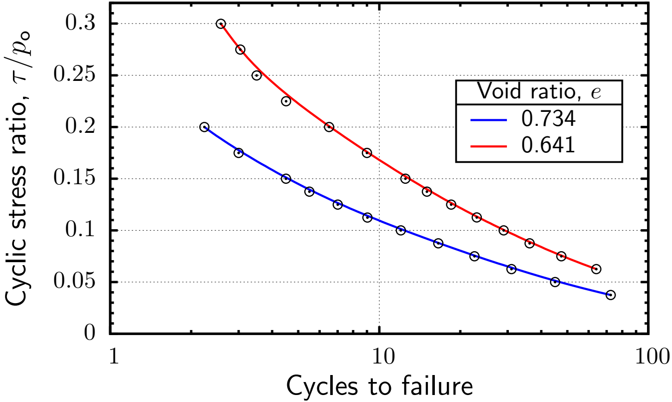


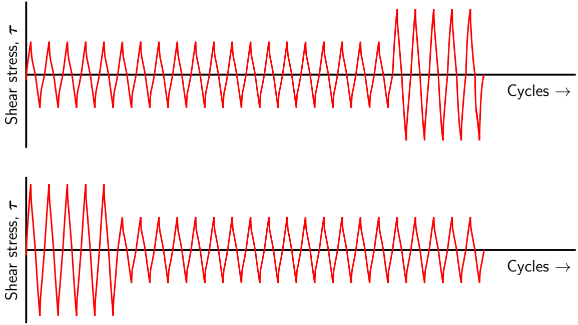
Case I: Uniform cyclic shearing

Liquefaction curves



Case II: Bi-amplitude cyclic shearing

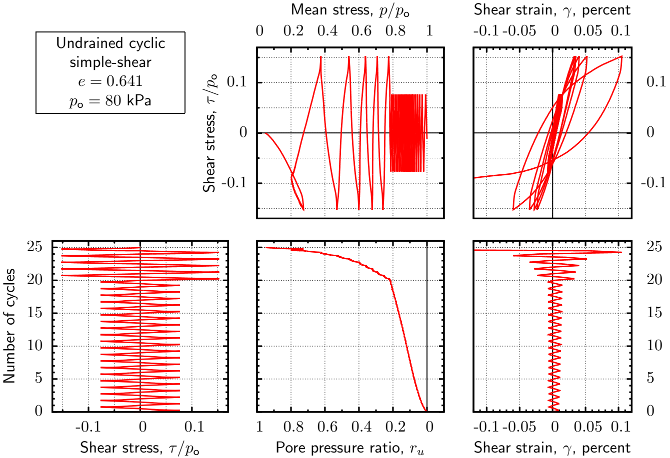
20 small-amplitude pulses & 5 double-amplitude pulses



Case II: Bi-amplitude cyclic shearing

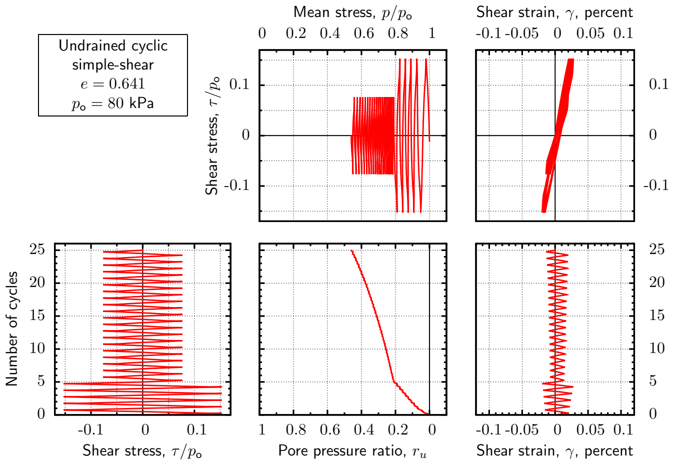
20 small-amplitude ⟶ 5 double-amplitude pulses

Undrained cyclic simple-shear
$e = 0.641$
$p_o = 80$ kPa



Case II: Bi-amplitude cyclic shearing

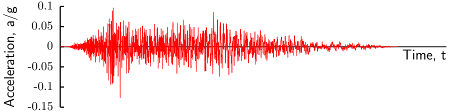
5 double-amplitude $\longrightarrow$ 20 small-amplitude pulses



Case III: Seismic shearing

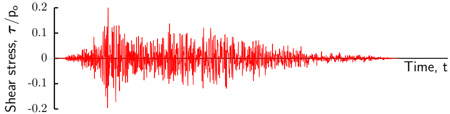
Select 24 sequences of seismic loading (Dr. Steven L. Kramer)

1. Earthquake ground accelerations from PEER data base



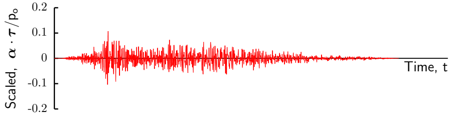
Landers, 1992
M = 7.3
`MCF000`

2. Create CSR, cyclic shear record (Dr. Kramer)



SHAKE91

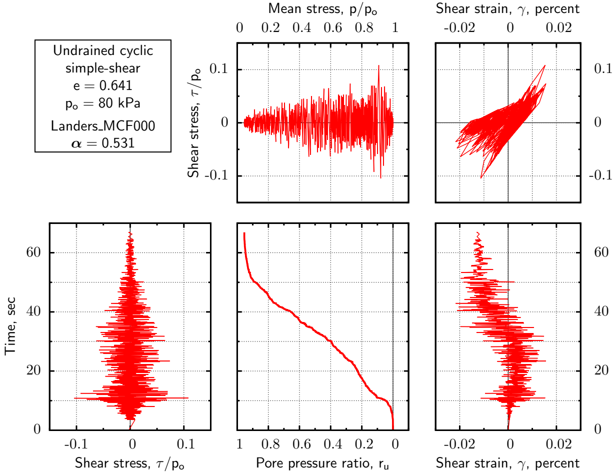
3. Scale the CSR to prolong pre-liquefaction



Scale factor:
$\alpha = 0.531$

Case III: Seismic shearing

Landers 1992 CSR record, scaling factor $\alpha = 0.531$



Severity Measures for cyclic loading

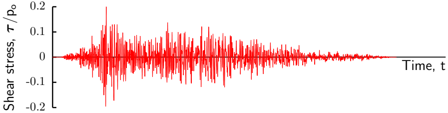
Ranking the severities, $1\,/\,\alpha$,
of 24 stress records,
as surmised from DEM simulations

Severity of the CSR record →

Record	Severity
CHICHI_CHY088-N_h2	2.398
KOCAELI_CNA000_h2	2.392
CAPEMEND_SHL090	2.262
CHICHI_TCU107-N_h2	1.965
ITALY_A-BRZ000	1.923
LANDERS_MCF000	1.883
COYOTELK_G06320	1.876
WHITTIER_A-CAM009	1.859
WHITTIER_A-116360	1.783
WHITTIER_A-WHD152	1.754
GREECE_E-PLK-NS	1.58
LOMAP_TIB290	1.577
COYOTELK_G04360	1.543
MAMMOTH_L-FIS090	1.517
LOMAP_A02043	1.499
WHITTIER_A-RO3000	1.42
COALINGA_H-COH090	1.416
BIGBEAR_HOS180	1.34
WHITTIER_A-ALT090	1.261
COALINGA_D-PVP360	1.227
PALMSPR_MVH135	1.124
HECTOR_12543090	0.864
NORTHR_VEN090	0.773
MAMMOTH_H-XMC207	0.553

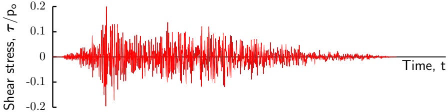
"Severity Measure":

- a scalar predictor of initial liquefaction
- computed from a cyclic stress (or strain) record



$\Longrightarrow$ Scalar value at initial liquefaction

Severity Measures



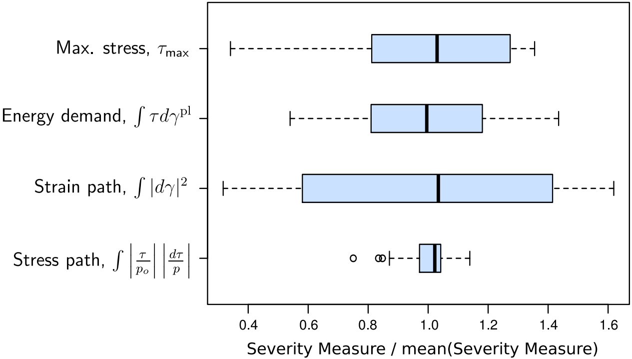
Possible Severity Measures for the 24 stress records:

- Maximum shear stress, $|\tau / p_o|_{\text{max}}$
- Energy demand, $\int \tau \, d\varepsilon^{\text{plastic}}$
- Strain path, $\int |d\varepsilon|^2$
- Stress path, $\int \left| \frac{\tau}{p_o} \right| \left| \frac{d\tau}{p} \right|$

Use DEM results to test the efficiency and sufficiency of each Severity Measure.

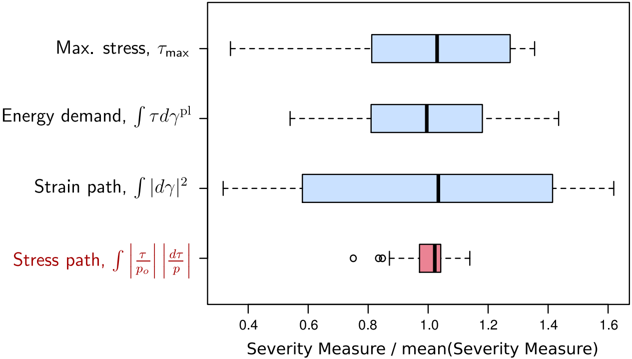
Severity Measures

Efficiencies of four Severity Measures: 24 cyclic stress records



Severity Measures

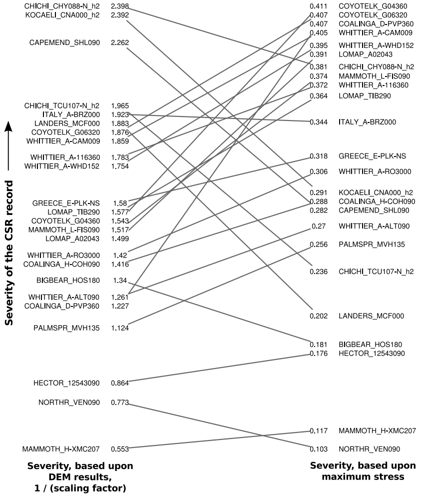
Efficiencies of four Severity Measures: 24 cyclic stress records



Severity Measures

Sufficiency of the Maximum Shear Stress as a Severity Measure:

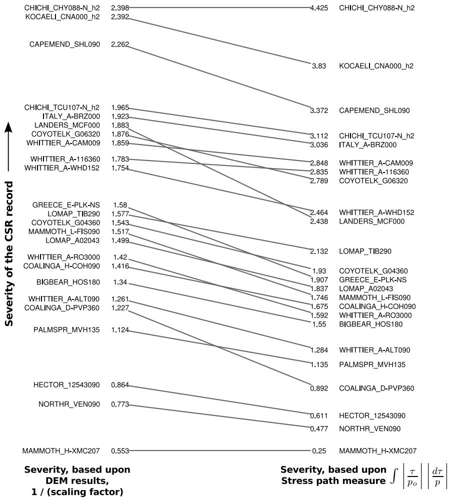
$|\tau/p_o|_{max}$



Severity Measures

Sufficiency of a
stress path scalar
as a Severity Measure:

$$\int \left|\frac{\tau}{p_o}\right| \left|\frac{d\tau}{p}\right|$$



Conclusion

Conclusion:

- Further work
- Future plans

Questions?