



# Micro-mechanically enhanced multi-yield surface modeling of drained sand behavior in dynamic boundary value problems

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## The research question

Seismic assessment of critical structures and geotechnical infrastructures has gained increased attention following major earthquakes in the history. Numerous assessment schemes, simple or complex, have been proposed since then to relate the expected performance of a structure of interest with the expected level of shaking intensity at its location. Among them, time history analysis proved itself to be the most interesting since it provides direct means to connect the seismic hazard with the dynamic response of an engineering structure, and metrics of risk.

It is well-known that the soil amplifications and the hysteretic damping affects the seismic demand on the structure. The nonlinear cyclic sand behavior is often represented by a phenomenological equation and a set of material internal variables. Relatively more straightforward models miss some of the most crucial soil behaviors, such as phase transformation, strain softening, and fabric effects, but enjoy numerical stability and low computational cost. In comparison, mathematically complex models capture the desired behavior but may suffer from convergence issues, a high computational cost, and a strenuous calibration procedure.

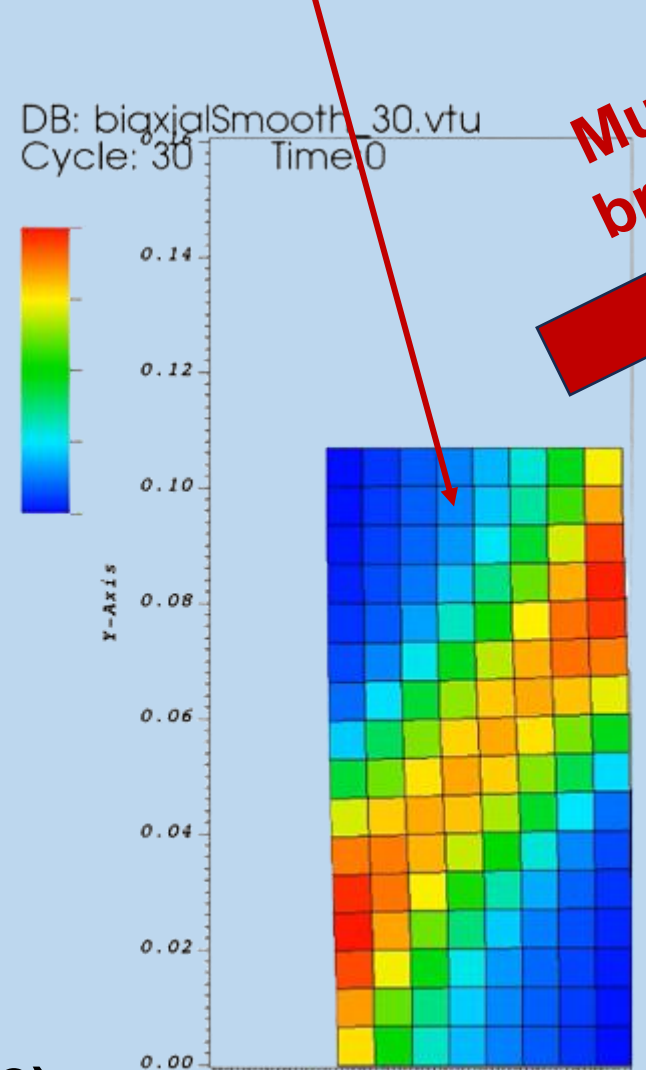
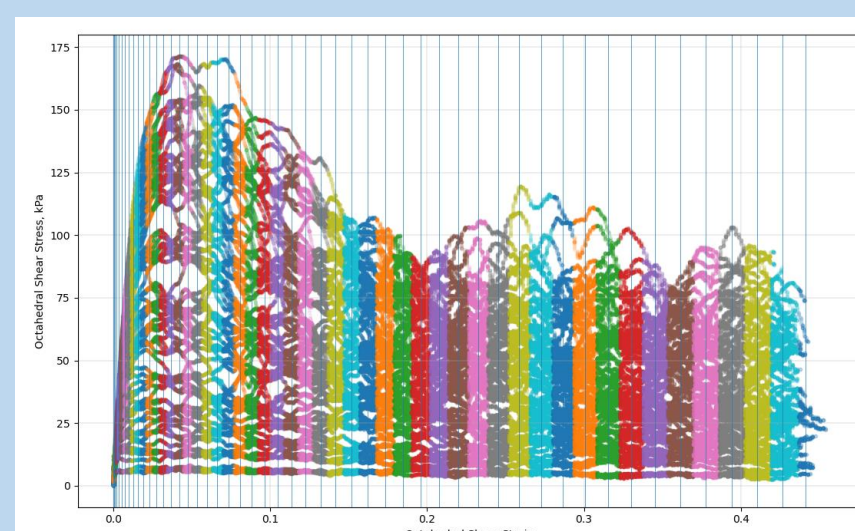
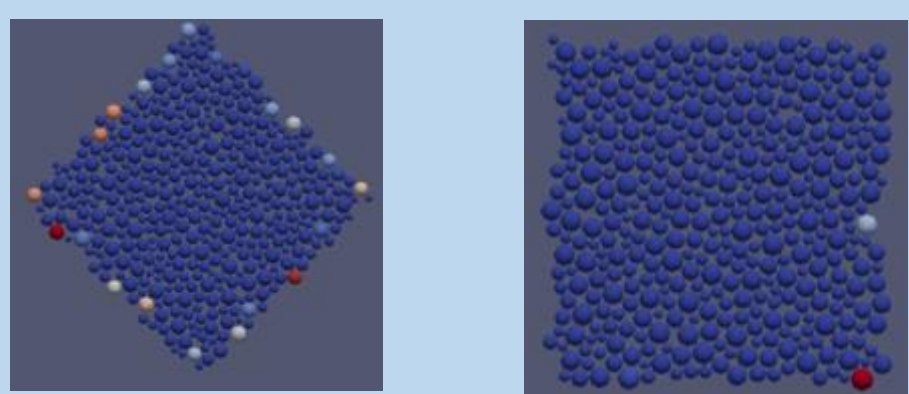
How can we efficiently include granular mechanics in the seismic assessment?

## Dynamic soil response through enriched constitutive equations

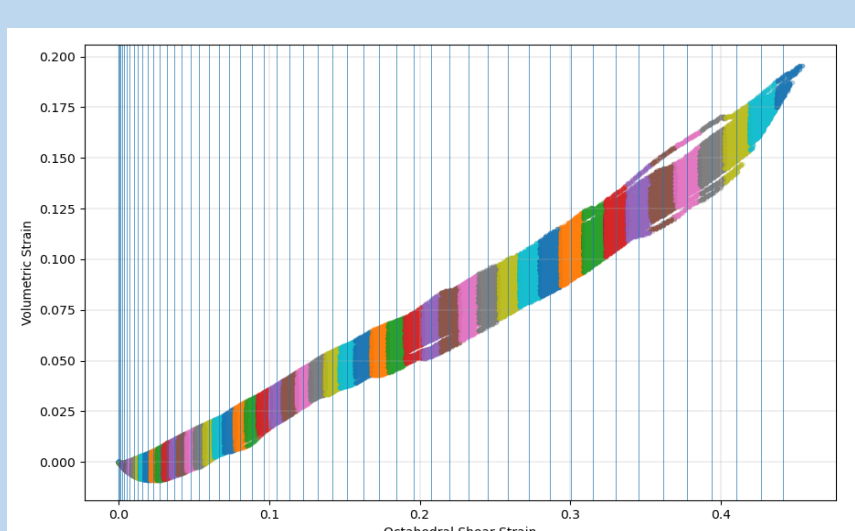
**Data-driven return mapping**  
(Karapiperis et al., 2021)

**Multiscale**  
(Guo & Zhao, 2014)  
(Andrade et al., 2011)

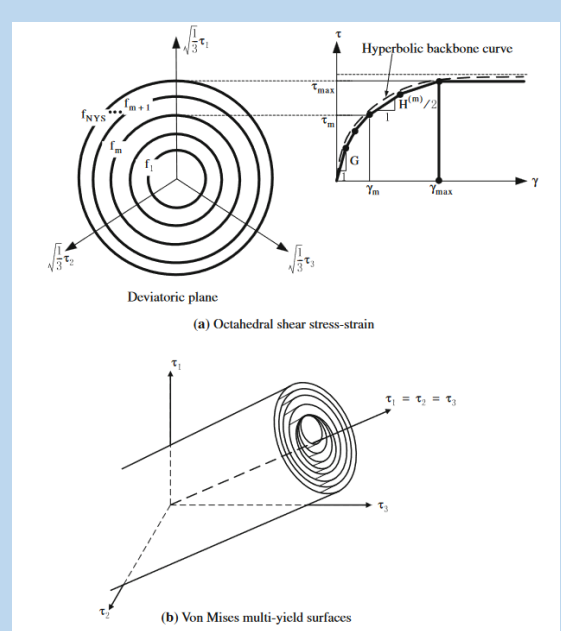
**Step 1)**  
Generate unit cell



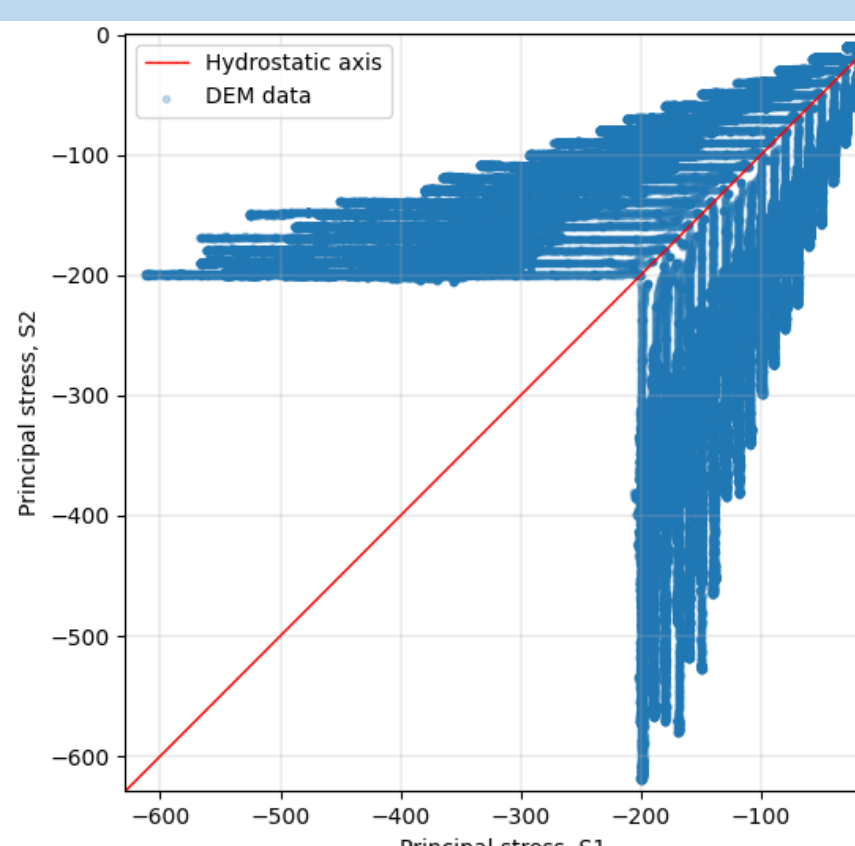
Multiscale bridging??



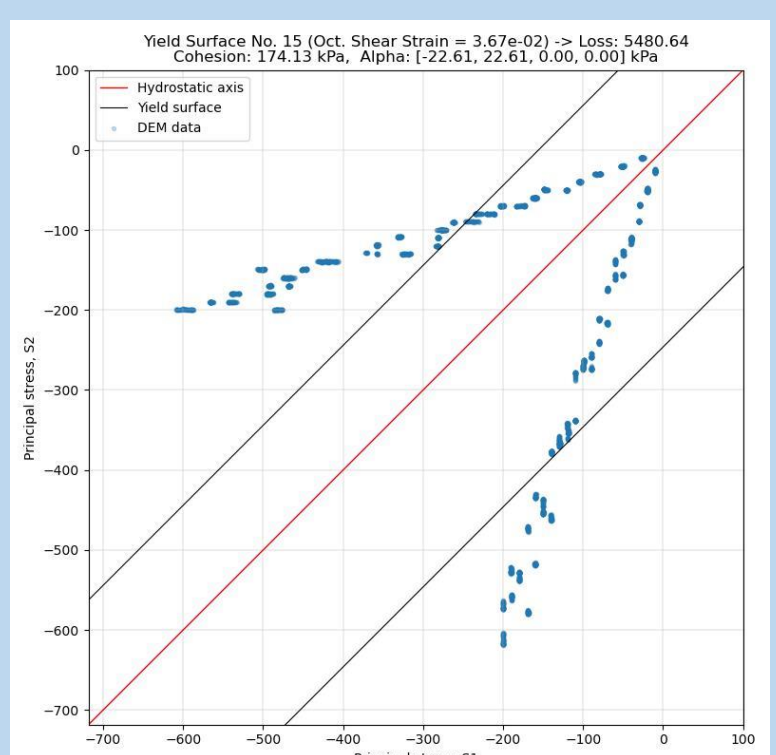
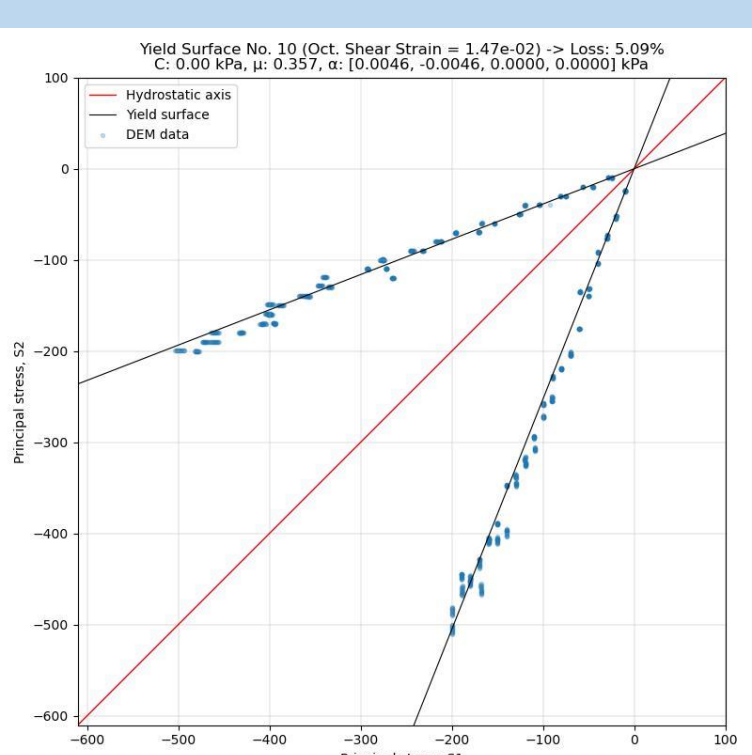
**Step 2)**  
Generate a database



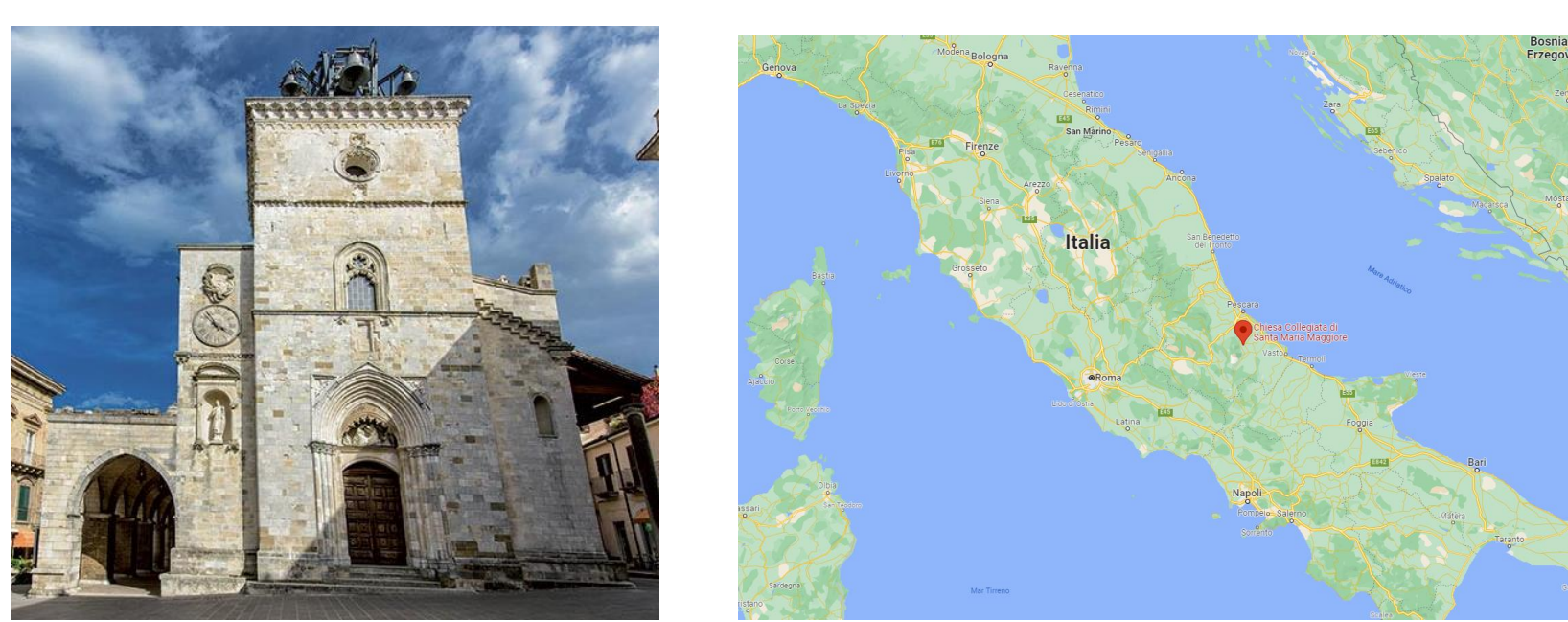
(Gu et al., 2011)



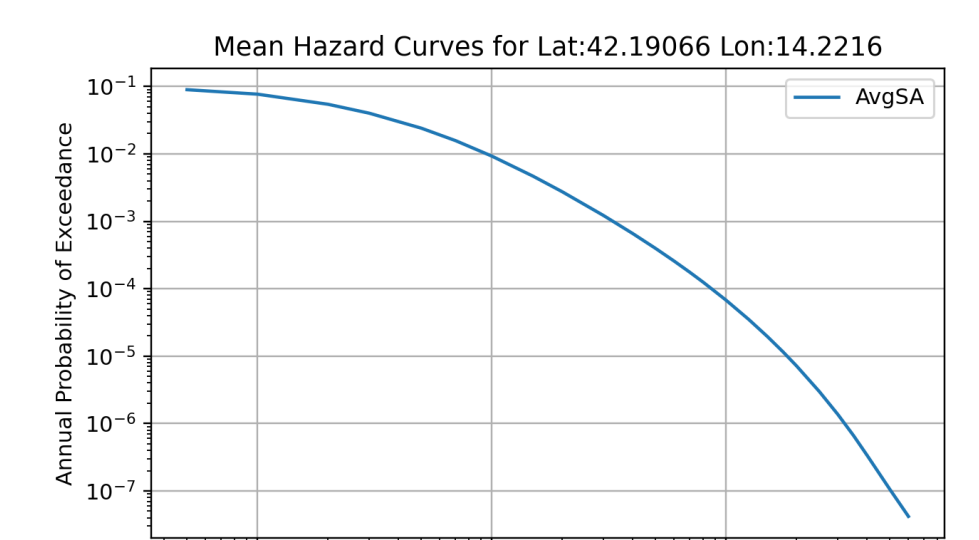
**Step 3)** Find yield surfaces based on data during the analysis



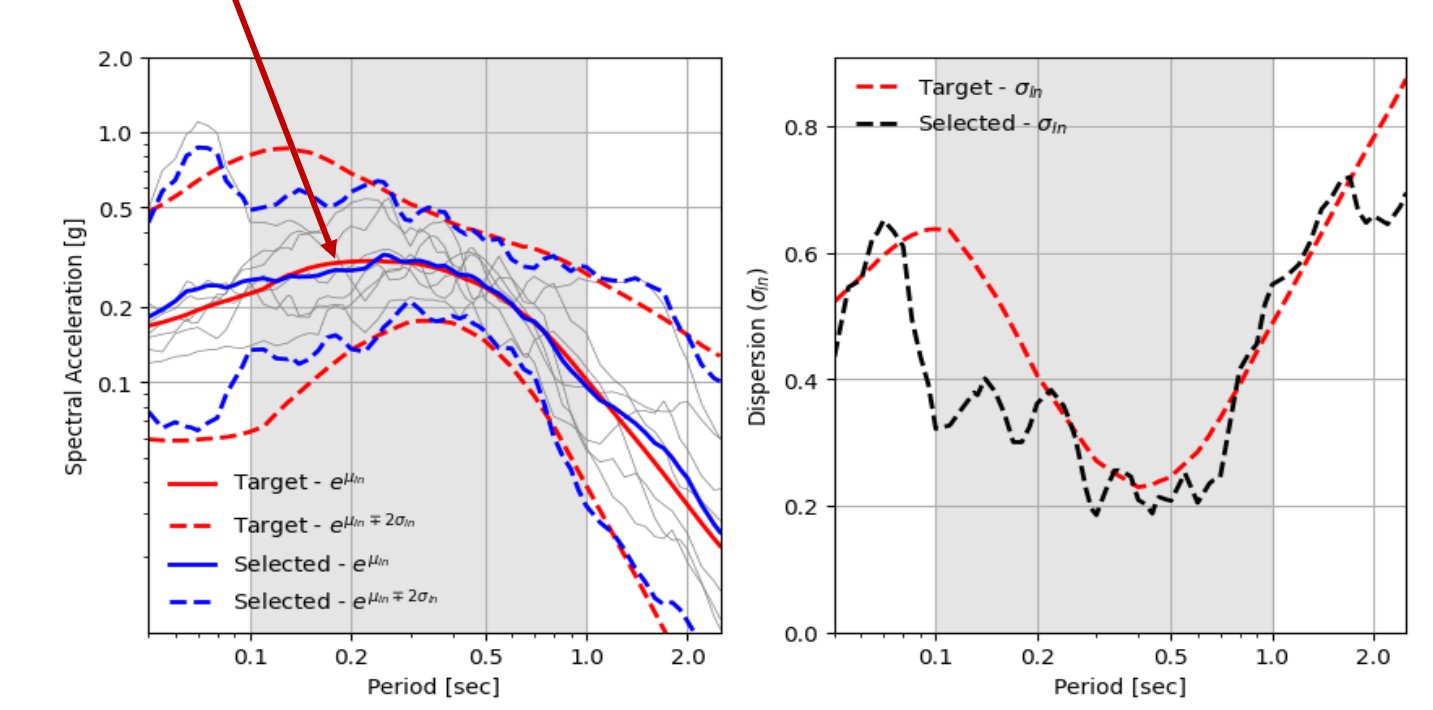
## Modelling of a seismic analysis problem: e.g. The bell tower of Guardiagrele



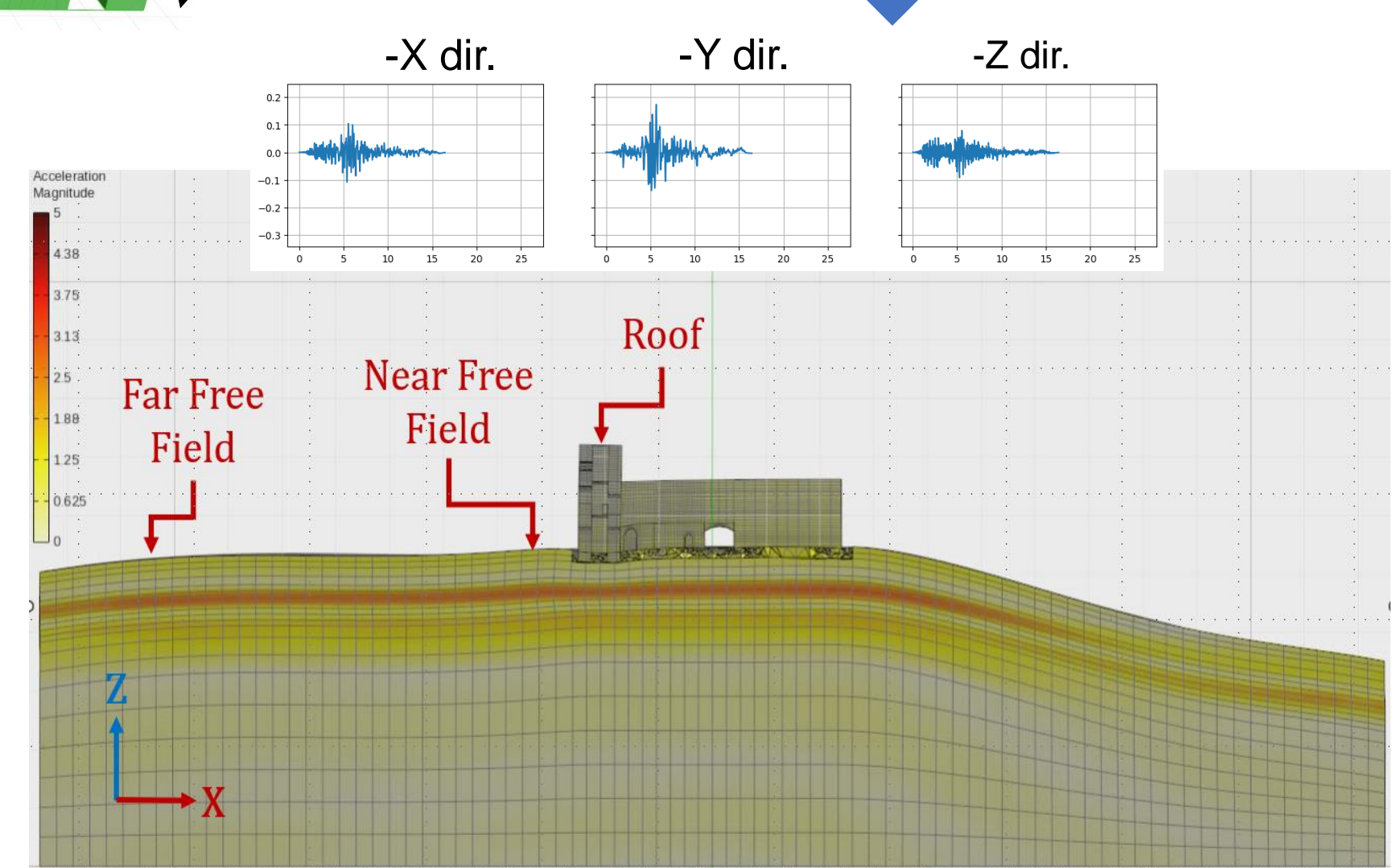
1 Seismic hazard at the site



2 Record selection

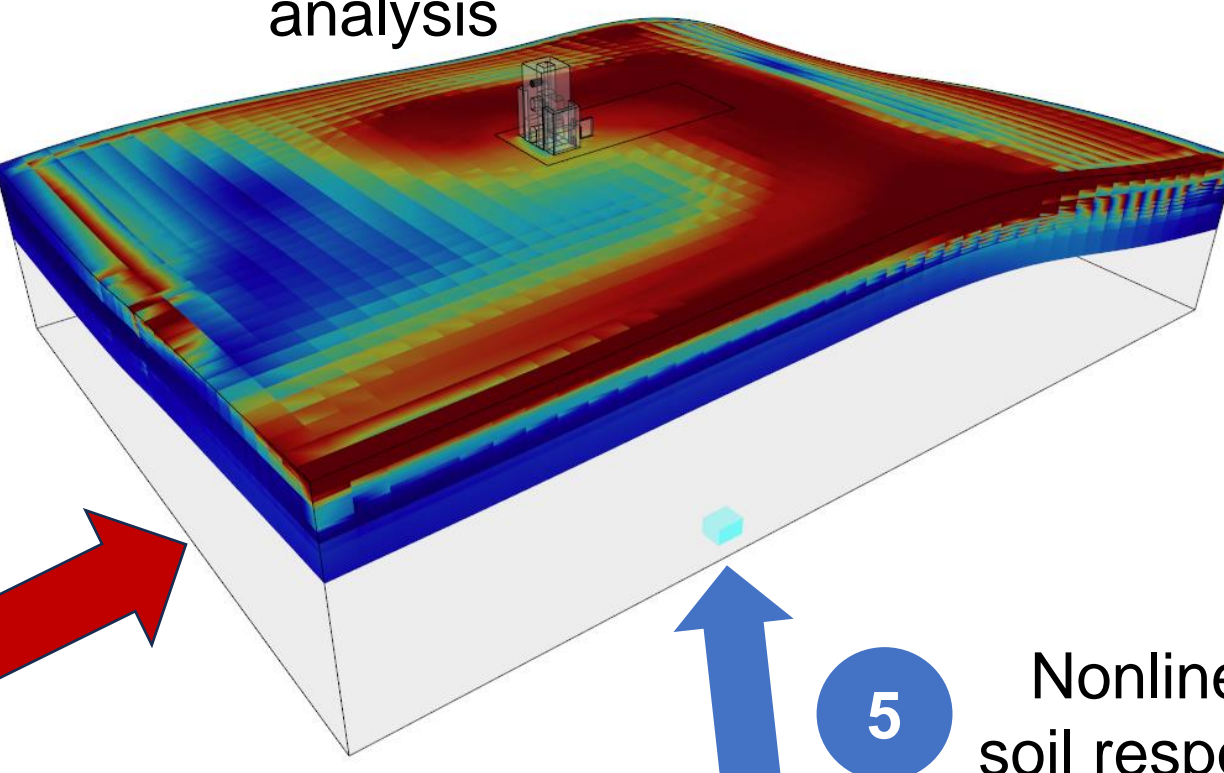


3 3-component acceleration



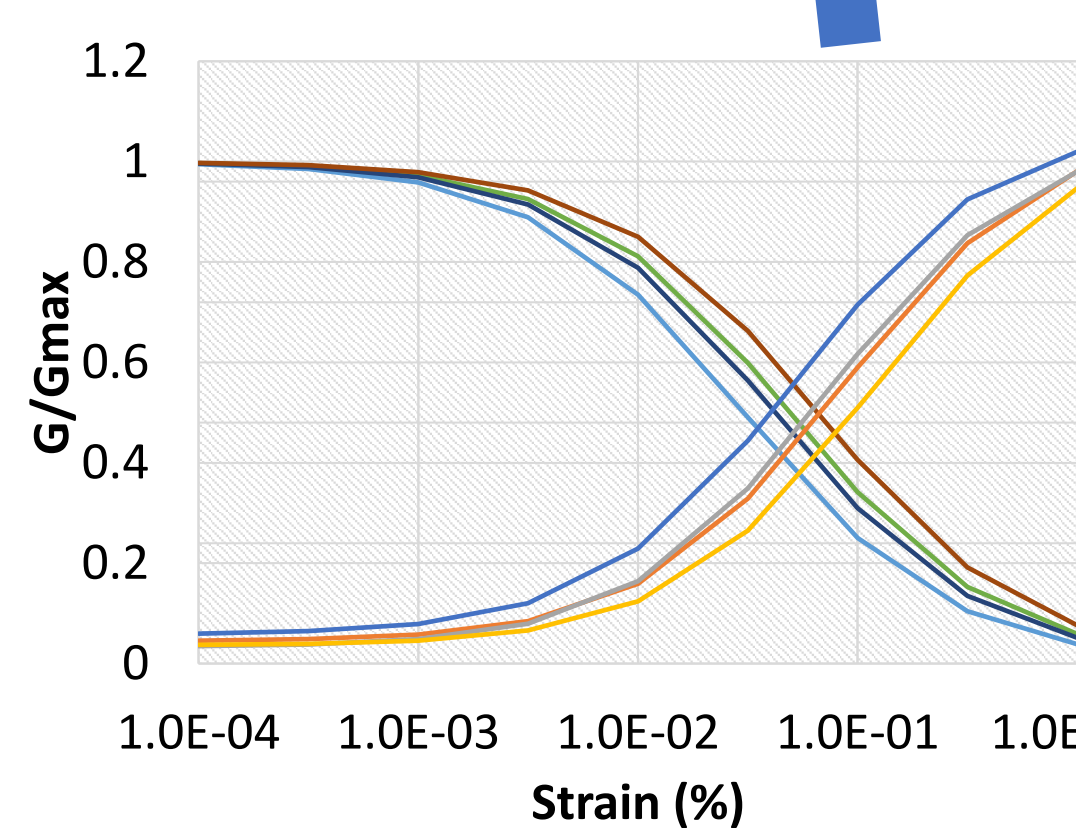
4 Finite element model  
250m x 175m x 46m  
STKO Pre-processor (Petracca et al.) + OpenSeesMP (McKenna et al.)  
26 Partitions & ~10,000 elements per thread

6 Initial state analysis

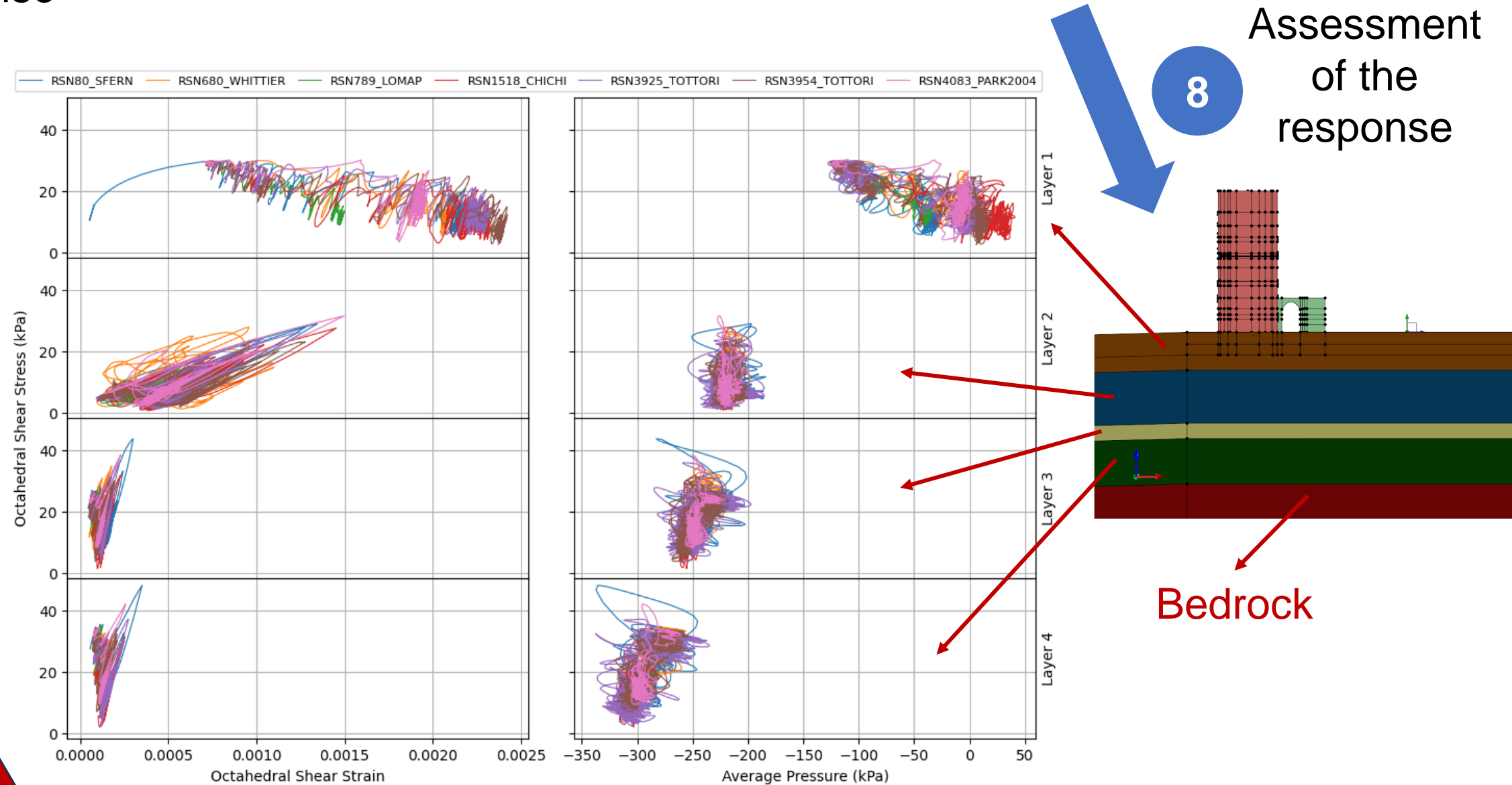


7 Time History Analysis  
Backbone + Damping

5 Nonlinear soil response



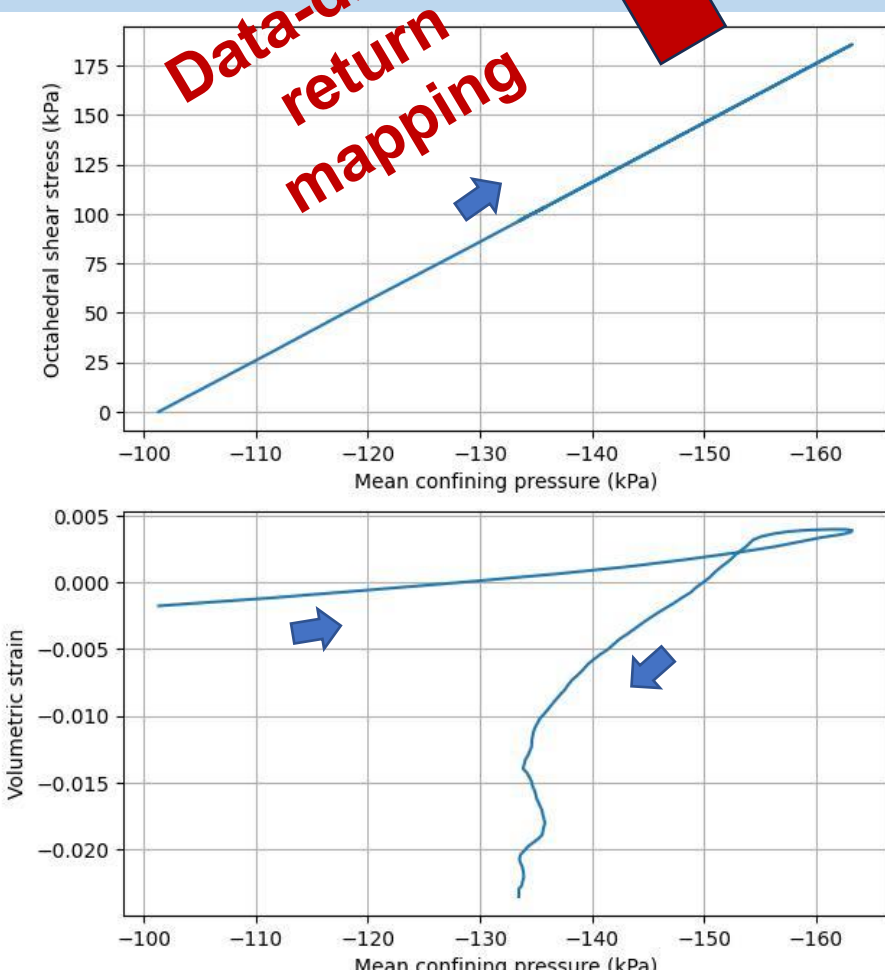
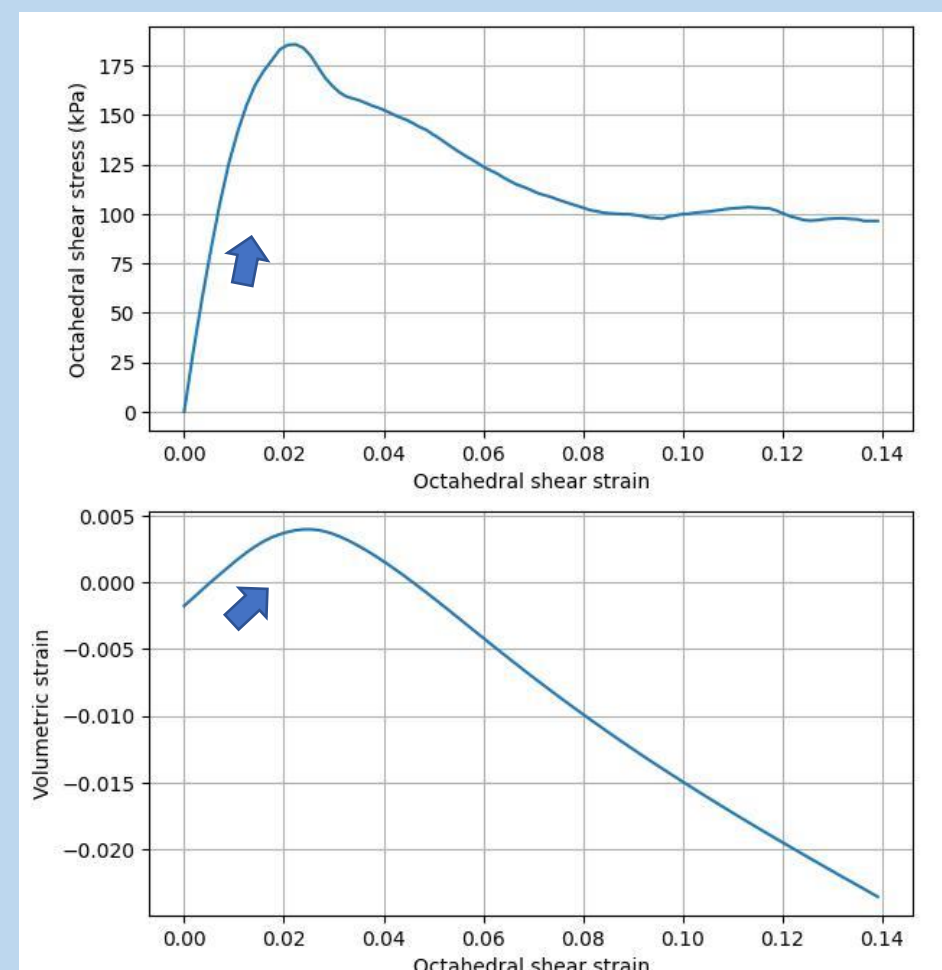
The classical multi-yield-surface material in OpenSees (Prevost 1985; Gu et al., 2011)



8 Assessment of the response

Multiscale bridging??

Data-driven return mapping



## Conclusions & Future

- The proposed approach captures the dilative-contractive transformation, strain hardening/softening, induced anisotropy, and anisotropy due to initial fabric.
- The model formulation results in a piece-wise linear modulus between yield surfaces, increased numerical stability and a mathematically simpler tangent operator.
- Cyclic analyses of the unit cell should be included in the database.

## References

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