ETH zürich

Schweizerischer Erdbebendienst
Service Sismologique Suisse
Servizio Sismico Svizzero
Swiss Seismological Service

EARTH OBSERVATORY OF SINGAPORE

OST Ostschweizer Fachhochschule

DERDW EARTH SCIENCES

Exploring fault preparation and earthquake nucleation from the laboratory

Patrick Bianchi[1], P. A. Selvadurai[1], L. Dal Zilio[2,3,4], A. Salazar Vásquez[1,5], C. Madonna[6], T. Gerya[2], S. Wiemer[1]

[1]Swiss Seismological Service, ETH Zurich; [2]Institute of Geophysics, ETH Zurich;
[3]Earth Observatory of Singapore, Nanyang Technological University; [4]Asian School of the Environment, Nanyang Technological University;
[5]University of Applied Sciences of Eastern Switzerland, Rapperswil; [6]Geological Institute, ETH Zurich

This presentation participates in OSPP

EGU

Outstanding Student & PhD candidate Presentation contest

1 Introduction

The initiation of **unstable fault slip** leading to earthquakes involves intricate physical processes and interactions. Investigations at both field and laboratory scales have highlighted the existence of **spatio-temporal variations in seismic or aseismic observations** near the epicenter of a major seismic event[1,2].

These variations are often associated with the **preparatory phase of major earthquakes** and are believed to involve processes resulting from **progressive localization of deformation,** around the eventual rupture zone, that **accelerates leading up to failure**. However, the time and spatial scales of this behavior are not well understood due to **our lack of understanding into the physical mechanisms within the preparatory zones**.

2 Material and methods

We perform a triaxial test on a sample of **Berea sandstone**. **16 piezo-electric transducers** (PZTs) are used **passively** to detect **acoustic emissions** (AEs) and **actively** to construct a **P-wave velocity model**. **Distributed strain sensing** (DSS) with **optical fibers** is employed to measure axial and circumferential strain (Fig. 1).
We conduct simulations using **H-MEC**[3], which is a 2D fully coupled and continuum based seismo-hydro-mechanical poro-visco-elasto-plastic numerical modeling code (Fig. 2). We track the **dissipation of mechanical energy**, which is related to **irreversible processes** consuming strain energy: $D = \sigma'_{ij} \cdot \dot{\varepsilon}'_{ij}$.

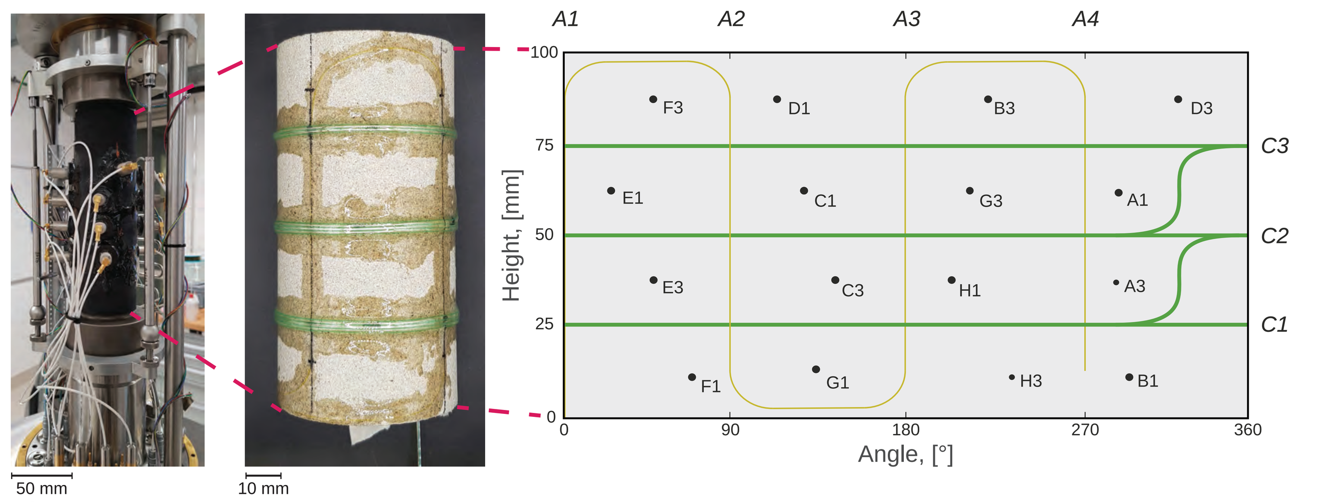

Figure 1

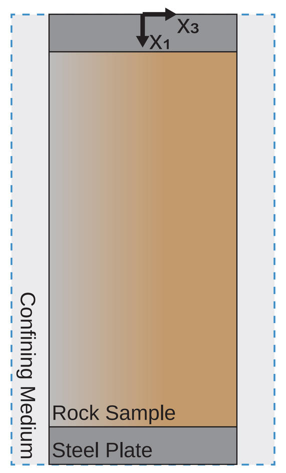

Figure 2

The following **protocol** is used:
- a **confining pressure** (blue line, Fig. 3) of **20 MPa** is applied to the sample and is kept constant,
- **differential stress** (red line, Fig. 3) is increased with a **constant piston displacement rate** (0.33 μm/s) until the **failure of the sample** is reached with associated major stress drop.

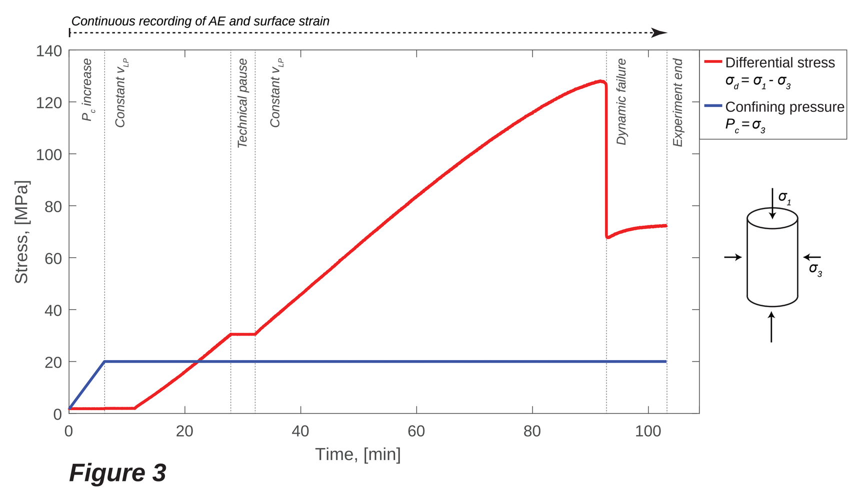

Figure 3

3 Laboratory Results

We observe the formation of **two clusters of AEs at the top and bottom of the sample** (Fig. 4) during approximately the entire test. Shortly (<5 min) before the macrofracture nucleation, the **AEs localize** on one side of the bottom half of the sample. Then, the macrofracture nucleates and propagates upwards.

The last interpolated DSS measurement of circumferential strain (Fig. 5) shows **deformation localization spatially correlating with the last cluster of AEs** that anticipated the nucleation of the macrofracture.

By repeatedly pulsing from each PZT sensor, we construct P-wave velocity models and investigate their **spatial variations** (Fig. 6). **Central regions** of the sample experience a **stronger velocity decrease** significantly earlier than the macrofracture nucleation. However, **no seismic activity** is detetced there before failure (Fig. 4).

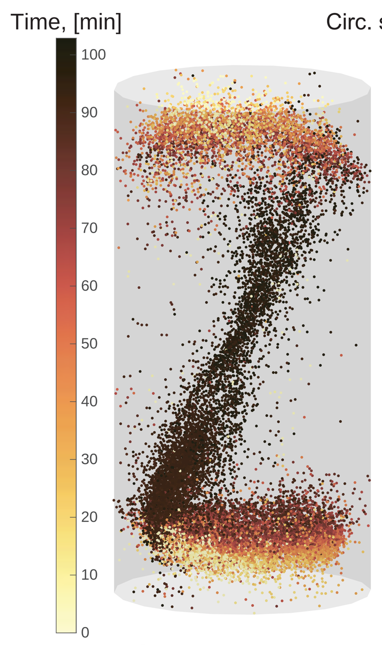

Figure 4

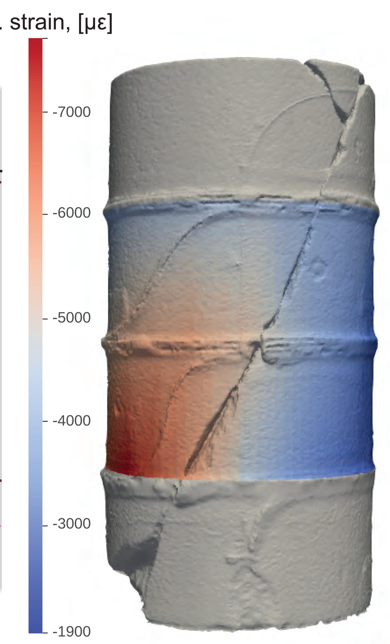

Figure 5

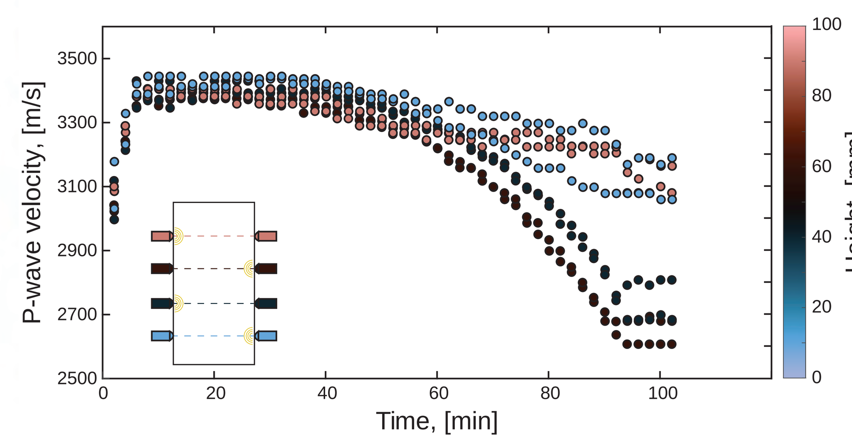

Figure 6

4 Numerical Results

We build a binary mask that isolate regions of the sample with **high dissipative levels** (Fig. 7) to track **irreversible deformation** in the sample. The simulations reveal **three distinct stages of preparatory processes:**

1) dissipative fronts propagate towards the middle of the sample correlating with the observed **AE locations** (Fig. 7, left)
2) dissipative regions are individuated in the middle of the sample and could be linked to the discernible **decrease of the P-wave velocities** (Fig. 7, middle)
3) a system of **conjugate bands** form, coalesce into a single band that grows from the center towards the sample surface and is interpreted to be due to the **preparation of a weak plane** (Fig.7, right).

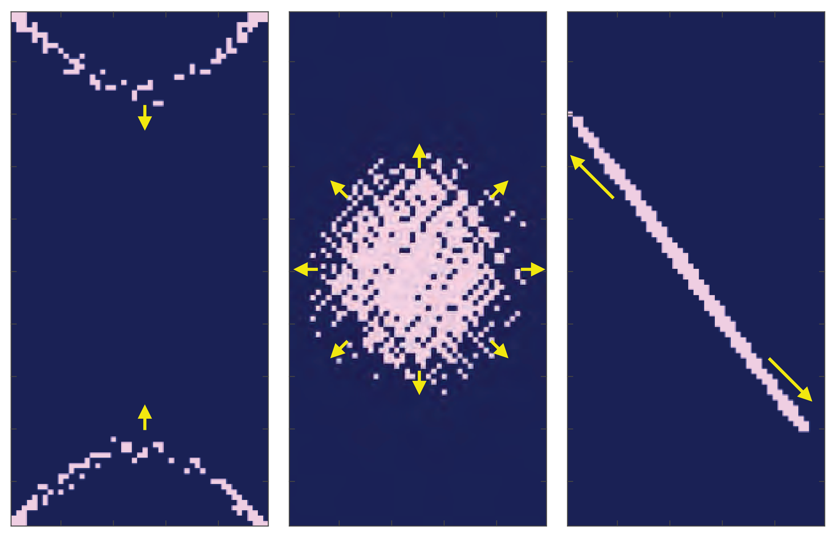
Figure 7

5 Discussion

The **mean volumetric strain rate and AE rate temporally correlate** and are both indicative for a **preparatory process** prior to the sample failure (Fig. 8, top). The increased seismic activity could be caused by the **localization of deformation**.

The **simulated dissipation** also shows an **abrupt increase** prior to failure (Fig. 8, bottom). The cause of this increase might be related to a **preparatory process** also responsible for the **acceleration** of the volumetric strain and AE rates. The model appears to capture this **accelerated behavior**.

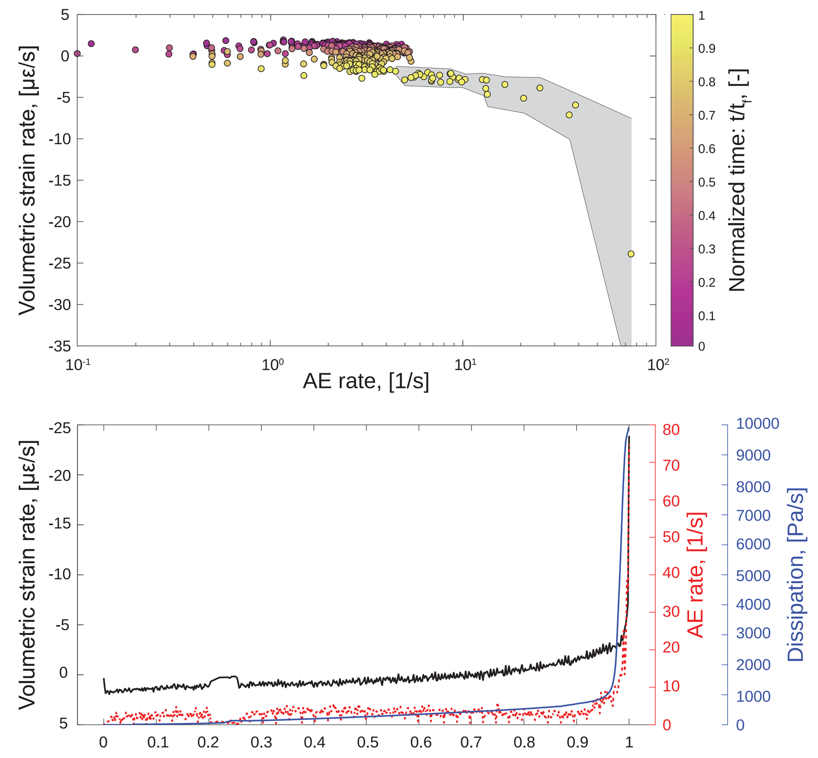

Figure 8

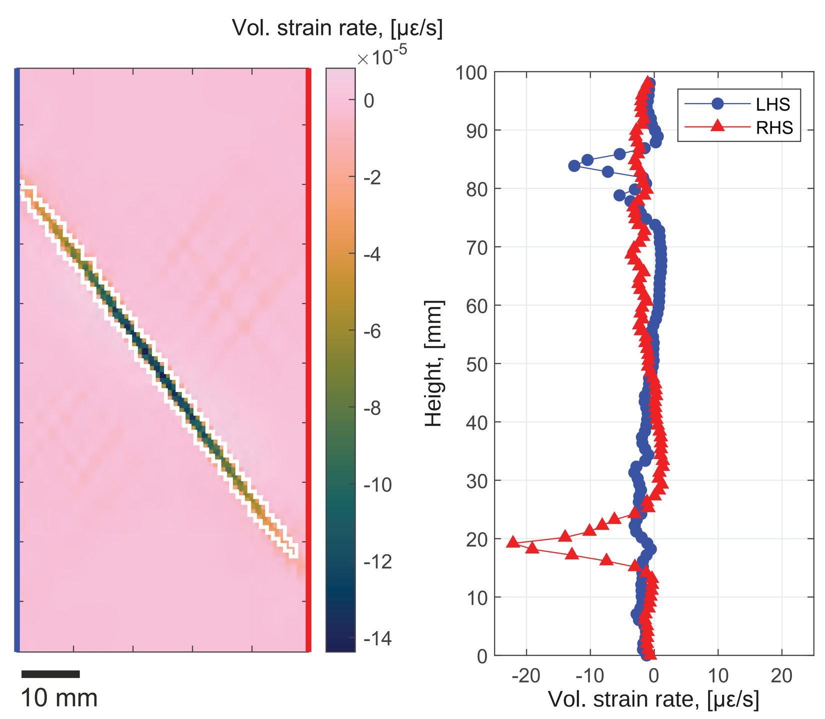

Figure 9

Volumetric strain rate localization is also observed **numerically** (Fig. 9) and spatio-temporally correlates with the laboratory observations. This process is observed as soon as the weak plane **approaches the sample surface** and **interacts** with it.

Due to our choice of using H-MEC in a **quasi-static** manner, our numerical results are deemed reliable only **up to the onset of fracture nucleation**; dynamic propagation is not currently considered in this investigation.

6 Conclusions

This study investigated both **aseismic and seismic preparatory processes linked to strain localization** preceding rock failure. **By combining laboratory measurements and numerical simulations**, we were able to capture a large variations of processes leading up to the nucleation of the shear fracture. **Developing models that capture a range of behaviors** at various scales, including the laboratory, is a necessary step **to properly upscale research efforts** to the reservoir and field scales.

References

[1] Kato, A., & Ben-Zion, Y. (2021). The generation of large earthquakes. *Nature Reviews Earth & Environment* , 2 , 26-39. doi: 10.1038/s43017-020-00108-w
[2] Campillo, M., & Paul, A. (2003). Long-Range Correlations in the Diffuse Seismic Coda. *Science*, 299 (5606), 547-549. doi: 10.1126/science.1078551
[3] Dal Zilio, L., Hegyi, B., Behr, W., & Gerya, T. (2022). Hydro-mechanical earthquake cycles in a poro-visco-elasto-plastic fluid-bearing fault structure. *Tectonophysics*. doi: https://doi.org/10.1016/j.tecto.2022.229516

RPMLab Rock Physics and Mechanics Laboratory

Swiss National Science Foundation