

LOTS:
1) LOT 1 – HIGH-LOAD BIAXIAL PRESS;
2) LOT 2 – INSTALLABLE VESSEL

English version

Document summary

This document defines the technical, functional, and safety requirements for a modular prototype biaxial machine for rock deformation (**DANTE**, **D**eformation **A**pparatus simulating **N**atural **T**ectonic stress **E**volution), divided into two lots:

- 1) **Lot 1 – Hydraulic Biaxial Press:** A hydraulic press capable of deforming rock samples up to **40 × 40 × 20 cm³** (clear working space between pistons **≥ 60 × 60 × 60 cm³**) along **two orthogonal axes (vertical and horizontal)**, each with a capacity of **≥ 1 MN**.
- 2) **Lot 2 – Installable Vessel:** A vessel for triaxial tests up to at least **80 MPa** on **Ø 40 mm** cylindrical samples (**height up to 100 mm**), providing feedthroughs for **≥ 12 strain gauges** and **≥ 8 piezoelectric sensors**. For example, it may be similar (but not limited) to an instrumented Hoek-type cell mounted in a uniaxial press.

“Modular” herein means the prototype can be used either (i) for biaxial experiments with custom sample holders (see Lot 1), or (ii) for triaxial experiments by inserting the pressure vessel (Lot 2).

Intended use: The system enables laboratory-scale reproduction of fault reactivation and earthquake generation under **controlled stress states**.

Installation site: The machine will be installed at the Laboratoire de Géologie de l'ENS, subject to the following weight and dimension constraints:

- Maximum floor load: **≤ 500 kg/m²**. A load-distribution platform shall be provided and installed if necessary.
- Maximum piece weight: **≤ 1 t** per individual subassembly, limited by the freight elevator.
- Overall dimensions: All subassemblies must be compatible with the freight elevator and with door access to the building and laboratories.
- Site visit: A site visit during the design phase is mandatory to verify access.

Delivery, installation, warranty, and maintenance: The supplier shall deliver and install the equipment at its final location, ready for operation, and shall provide:

- Documentation & training: Complete documentation (user/maintenance manuals, electrical/hydraulic schematics) and on-site operator training upon delivery.
- Warranty: A minimum 12-month comprehensive warranty covering all parts, starting from site acceptance. Provide technical support during the warranty period.
- Optional maintenance. An optional maintenance and extended-warranty contract available through 30/06/2029.

Acceptance: Final acceptance will follow successful on-site functional tests demonstrating compliance with these specifications.

LOT 1: HYDRAULIC BIAXIAL PRESS – HIGH LOAD

1. Project summary

The project involves developing of a new and unique biaxial apparatus capable of deforming rock samples up to $40 \times 40 \times 20 \text{ cm}^3$ (Figure 1a). The sample will include a saw-cut that can be oriented at different angles relative to the loading axes. The sample holder must allow at least the following angle combinations relative to the vertical and horizontal axes: 30° - 60° , 40° - 50° , 50° - 40° , and 60° - 30° (Figure 1c).

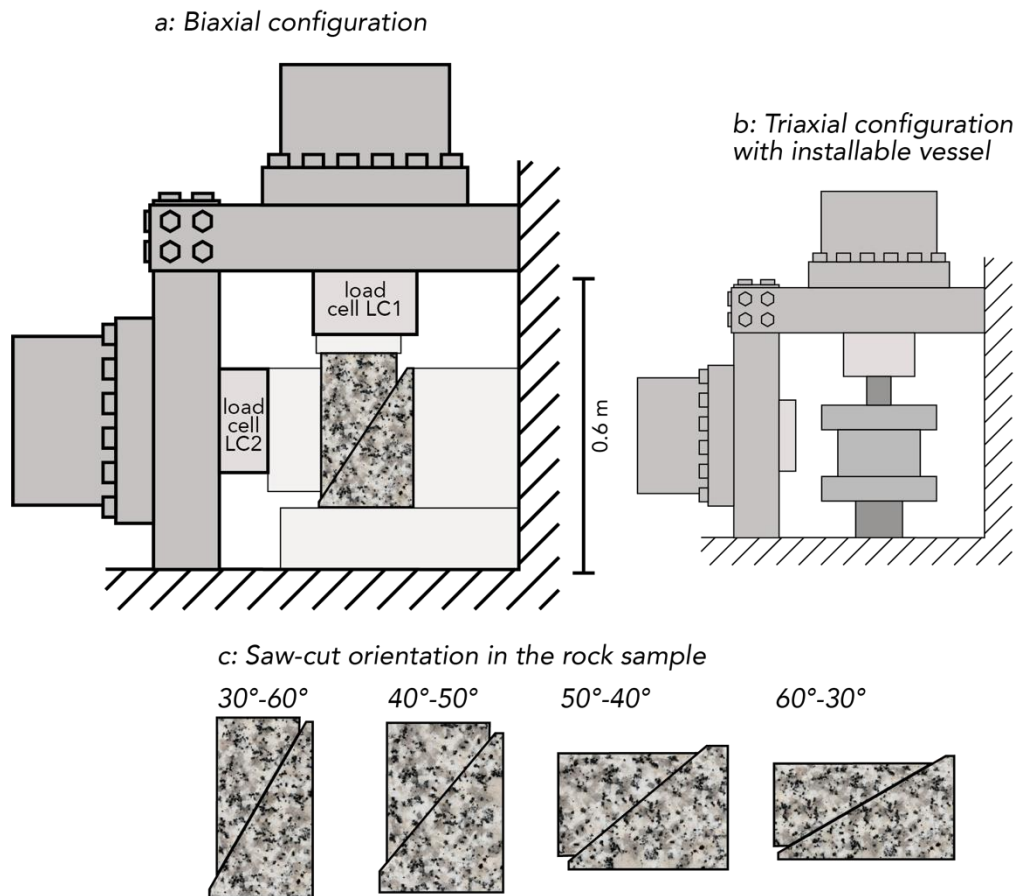


Figure 1. Sketch of the prototype showing the purposes. a) biaxial configuration; b) triaxial configuration (see also Lot 2); c) saw-cut orientations in the rock sample for biaxial configuration.

The scientific purpose is to reproduce the earthquake phenomenon at laboratory scale under controlled stress conditions representative of different tectonic settings. The saw-cut serves as an analogue for a natural fault. The apparatus comprises two orthogonal axes—one vertical and one horizontal—each capable of applying up to **1 MN**. This corresponds to a nominal stress of up to **12.5 MPa when applied to the $40 \times 20 \text{ cm}^2$ lateral faces** of the largest sample. The vertical and horizontal loads will be

used to represent the maximum and minimum principal stresses acting in the Earth's crust.

In addition, the apparatus must accommodate the integration of an installable vessel (see Lot 2) to be used with the vertical axis to conduct triaxial experiments (Figure 1b).

2. Technical specifications

2.1 General specifications:

- The apparatus shall comprise two hydraulic rams, one vertical and one horizontal.
- The two rams shall be precisely aligned to ensure perpendicularity (orthogonality).
- The supporting frame shall be high-stiffness steel, designed to maintain orthogonality under load.
- Each axis shall be equipped with:
 - 1) a load cell installed between the piston and the sample assembly, in direct contact with the sample assembly; and
 - 2) at least one displacement sensor (LVDT and/or optical encoder).
- The vertical and horizontal axes shall have independent closed-loop control.
- Each axis shall support force control (load cell as feedback/setpoint) and displacement control (displacement sensor as feedback/setpoint).
- The system shall operate at room temperature.
- The system shall include a control system and a data-acquisition system.

2.2 Expected mechanical and control performances

- Sample size and working space: accommodate samples up to $40 \times 40 \times 20 \text{ cm}^3$; clear working space between rams $\geq 60 \times 60 \text{ cm}^2$; internal frame dimensions $\geq 60 \times 60 \times 60 \text{ cm}^3$.
- Load capacity: horizontal and vertical axes up to 1 MN each.
- Full load scale should be reached within a single intensifier stroke, if present.
- Load control modes for each axis:
 - 1) Force control with a constant setpoint; or
 - 2) Load-ramp control (ramp rates 50 N/s to 5 kN/s); or
 - 3) Sinusoidal force oscillations (amplitude range: 0.5 – 5 kN; frequency range: 0.001 Hz – 1 Hz)while the sample deforms.
- Low-load stability: reliable control at small targets, $\leq 100 \text{ N}$.
- Stroke: minimum 100 mm (10 cm) on both horizontal and vertical axes.
- Velocity control mode for each axis:
 - 1) Piston velocity controllable up to $\geq 1 \text{ mm/s}$ with fine control down to $\approx 5 \text{ nm/s}$;
 - 2) Capability to apply sharp, one-order-of-magnitude velocity changes, i.e. step changes (e.g., $1 \text{ }\mu\text{m/s}$ to $10 \text{ }\mu\text{m/s}$, $10 \text{ }\mu\text{m/s}$ to $100 \text{ }\mu\text{m/s}$, $100 \text{ }\mu\text{m/s}$ to $1000 \text{ }\mu\text{m/s}$).

- 3) When velocity = 0, the position shall be held (the force on the rock may evolve with sample deformation).

2.3 Sample holder requirements

- Material: High-stiffness steel (or equivalent) to ensure minimal deformation under load.
- Sample geometries: Accommodate different sample sizes and allow the saw-cut fault plane to be oriented, relative to the vertical and horizontal axes, at 30°–60°, 40°–50°, 50°–40°, and 60°–30°, respectively. This may be achieved with one adjustable sample holder or a set of interchangeable sample holders.
- Maximum sample size: 40 × 40 × 20 cm³. Holders and spacers shall also be compatible to, or provided also for, the smallest sample (10 × 10 × 5 cm³).
- Minimum sample size: 10 × 10 × 5 cm³.
- Saw-cut contact area: The two-block assembly shall be designed such that one block is slightly smaller and positioned to maintain a constant contact area while it slides over the other (see Figure 1c). The assembly shall allow along-fault displacement of ≥ 30 mm (3 cm).
- Bidirectional motion: The sliding block shall be capable of moving upward or downward, depending on the experimental force configuration.
- Low-friction guidance: Integrate nominally frictionless guiding surfaces between the sample holder and the load-cell/piston (e.g., linear guides/ball bearings or engineered low-friction materials or lubricants - e.g., Glycodur ® or Molykote ®) to allow sample/sample-holder position adjustment during loading.
- Handling: Provide a safe loading/unloading system (e.g., fixtures, lifting/positioning aids) for installing and removing the sample holders and rock specimens within the apparatus.

2.4 Data acquisition and control system

- The system shall include a PC-based controller for experiment programming via a dedicated software interface or LabVIEW.
- Data visualization shall be real-time.
- Each axis shall be controllable independently in: 1) position-hold mode (velocity = 0), using the displacement sensor as the setpoint; 2) velocity mode, using the displacement sensor as the setpoint; 3) force mode, with a target value (kN) using the load cell as the setpoint; 4) force-ramp mode, with a ramp rate (kN/s) using the load cell as the setpoint; 5) force-oscillation mode.
- A global sampling rate selectable from 1 Hz to 1 kHz shall apply to all enabled channels, with continuous, time-stamped logging.
- Each channel's acquisition shall be enabled or disabled individually. Channels shall include all the sensors installed on the press: horizontal force, vertical force, horizontal displacement, and vertical displacement.
- The system shall provide at least two spare input channels to allow connection and acquisition from auxiliary displacement sensors (e.g., LVDTs or other sensors mounted directly on the sample).

- The system shall include an output synchronization clock to enable time synchronization of the acquired data with external acquisition systems.

2.5 Safety

- The hydraulic power unit (pump/motor) shall be certified and calibrated.
- The equipment shall be certified and calibrated for pressure (hydraulic rams), force (each load cell), and displacement (each sensor) on both axes, with traceable certificates.
- The system shall include plexiglass safety guards on all accessible sides.
- End-of-travel safety: both axes shall be equipped with limit switches; upon activation, piston motion shall stop immediately.
- Software limits: configurable limits on both axes for ram position, ram speed, and applied force; when a limit is reached, the ram shall hold position.
- Maximum force limit: a configurable software maximum force; if the limit is reached or exceeded, hydraulic power shall shut off.

LOT 2: INSTALLABLE VESSEL WITH FEEDTHROUGHS FOR STRAIN GAUGES AND PIEZOELECTRIC SENSORS

1. Project summary

The project covers the design and supply of an installable vessel to deform cylindrical rock specimens **Ø 40 mm** and height up to 100 mm under confining pressure up to **80 MPa**. The cell shall incorporate electrical feedthroughs for internal instrumentation: **≥ 12 axial feedthroughs** for strain gauges and **≥ 8 coaxial (shielded) feedthroughs for piezoelectric (AE) sensors**.

The installable vessel will interface with the vertical ram of the biaxial press (Lot 1) to enable triaxial experiments.

In standard configuration, the confining oil pressure represents the minimum principal stress and the vertical ram applies the maximum principal stress. The installable vessel shall also allow the alternate configuration in which the maximum principal stress while the vertical ram applies minimum principal stress, enabling earthquake simulations across a broader range of tectonic stress regimes using saw-cut (faulted) cylinder specimens.

2. Technical specifications

2.1 General specifications:

- The installable vessel shall fit in the working space, internal frame dimensions $\sim 60 \times 60 \times 60 \text{ cm}^3$.
- The installable vessel shall incorporate electrical feedthroughs providing at least 12 axial channels for strain gauges and at least 8 shielded coaxial channels for AE sensors.

- The top and bottom end-platens shall be equipped with three-component acoustic stations, comprising one compressional (P-wave) and two mutually orthogonal transverse (S-wave) polarizations, with resonant frequency >2.5MHz, and isolated from oil pressure.
- A confining-pressure hydraulic pump/power unit shall be supplied, complete with reservoir, filtration, and, if required, cooling.
- The confining medium shall be oil.
- Confining pressure shall be measured with calibrated pressure transducer supplied with traceable certificates; the system shall also provide oil volume-change measurement, likewise calibrated.
- Safe handling and integration shall be ensured by fixtures, lifting/positioning aids, and protective features for installing and removing the vessel within the apparatus.
- The system shall include control and data acquisition.
- Integration with Lot 1: if Lots 1 & 2 are supplied together, the control and data acquisition shall be fully integrated into the biaxial press system.

2.2 Expected mechanical and control performances

- Pressure rating: stable operation up to 80 MPa confining pressure.
- Full pressure scale should be reached within a single intensifier stroke, if present.
- Pressure control modes:
 - 1) Constant-pressure setpoint with minimum resolution of 10 kPa; or
 - 2) Pressure-ramp with programmable rates from 10 kPa/s to 1 MPa/s, while the specimen deforms.
- Flow-rate control mode:
 - 1) Flow-rate control in mm³/s; or
 - 2) Hold-position with flow rate = 0.
- Low-pressure stability: reliable control at small targets, ≤ 100 kPa.

2.3 Data acquisition and control system

- The system shall include a PC-based controller for experiment programming via a dedicated software interface or LabVIEW.
- Data visualization shall be real-time.
- Pump shall be controllable in: 1) pressure mode; 2) pressure-ramp mode; 3) flow-rate mode (mm³/s); 3) hold-position mode (flow rate = zero).
- Sampling rate shall be selectable from 1 Hz to 1 kHz, with continuous, time-stamped logging.
- Acquired channels shall include pressure, oil volume, and acoustic measures for compressional and transverse elastic waves.
- The system shall include an output synchronization clock to enable time synchronization of the acquired data with external acquisition systems.

2.4 Safety

- The hydraulic power unit (pump/motor) shall be certified and calibrated.
- The pump shall be equipped with limit switches; upon activation, pump motion shall stop immediately.

- Software limits shall be configurable for pressure, pump position, and pump speed; when a limit is reached, the pump shall hold position.
- Software maximum-pressure shall be configurable; if reached or exceeded, hydraulic power shall shut off.
- Over-pressure protection shall be provided by a rupture disk on the pressure line.