A Biaxial Plane Strain Apparatus for Neutron Diffraction-based Experiments on Granular Rocks

Athanasopoulos, Stefanos; Hall, Stephen; Nordin, Axel; Nikoleris, Giorgos; Couples, Gary; Kelleher, Joe; Pirling, Thilo

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S.D. Athanasopoulos [1], S.A. Hall [1,2], A. Nordin [3], G. Nikoleris [3], G. Couples [4], J.F. Kelleher [5], T. Pirling [6]

[1] Division of Solid Mechanics, Lund University, Lund, Sweden
[2] European Spallation Source AB, Lund, Sweden
[3] Division of Product Development, Lund University, Lund, Sweden
[4] Institute of Petroleum Engineering, Heriot-Watt University, Edinburgh, United Kingdom
[5] ISIS, Rutherford Appleton Laboratory, Chilton, Didcot, United Kingdom
[6] Institut Laue Langevin, Grenoble, France

Overview

A new **"plane-strain" biaxial loading device** for granular rocks that allows the full-field investigation of **strain evolution at different scales** is introduced.

➔ **A combination of approaches** is required.

Neutron Diffraction

Successfully used by Hall et al. (2011) and Wensrich et al. (2012) for grain-strain measurement and force/stress distribution in granular materials under load.

DIC

Measurement of total strains, including porosity changes.

➔ **Neutron Diffraction to map spatial varations and evolution of granular strains** in rocks under loading and to investigate **how forces are transmitted and evolve with deformation.**

➔ **Simultaneous** use of **DIC** will aid the characterisation of the **mechanisms that act at different stages of deformation**.

"Plane-Strain" Specifications & Device MKII Optimisation Main Features

"Plane-Strain" Conditions (Fig.1):

- **Force applied** along **Z axis** by using one moving piston (2nd piston is fixed).
- **Deformation limited** to evolve only in **X-Z plane** by using:
  - ➔ a pair of pressure controlled deformable fluorinated membranes.
  - ➔ rigid sapphire glass plates
- **No deformation allowed** on **Y axis** by using rigid sapphire glass plates.

Device Optimisation Main Goal

➔ To **combine** the design **demands** of the **Neutron Measurements** and of the **High Pressure** needed (realistic in-situ conditions):

- **Main body** built out of **ALU 7075-T6** for **high strength** and **low neutron attenuation**.
- **Walls normal to X axis** (Fig.1) as **thin** as possible **for better neutron penetration** but **thick** enough **to sustain 10 MPa** confining pressure.

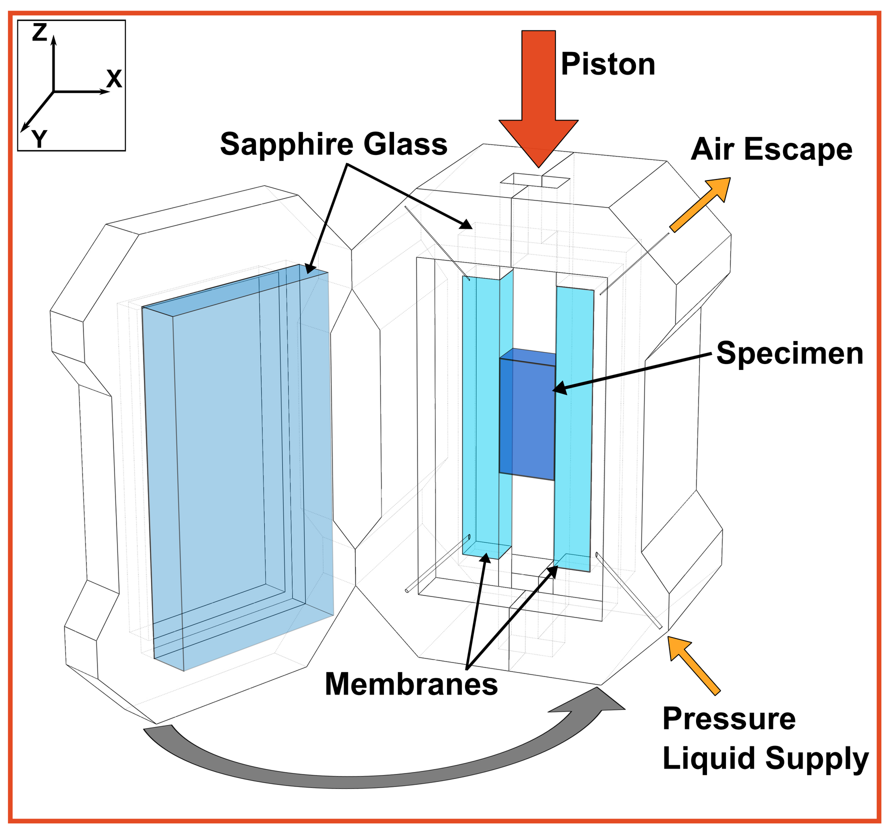

Figure 1. Initial schematic of the prototype "plane-strain" biaxial loading device.

* The optimisation of the apparatus (MKII) was realised with ANSYS 15.0

Proof-of-Concept Experiment

First **proof-of-concept experiment** realised using ENGIN-X (Fig.2) at ISIS (UK):

- **Prismatic samples** (Fig.3 - Inset a) of Fontainebleau NE 34 **sand** (210 μm average grain size).
- **Load-unload** cycle (Fig.3) **without confining pressure** (Device MKI).
- **2D grid** of **30 points**, using a **3x3x18 mm^3 gauge volume** (Fig.3 - Inset a).
- **Simultaneous** measurement of **2 directions of strain** (Fig.3 - Inset a).

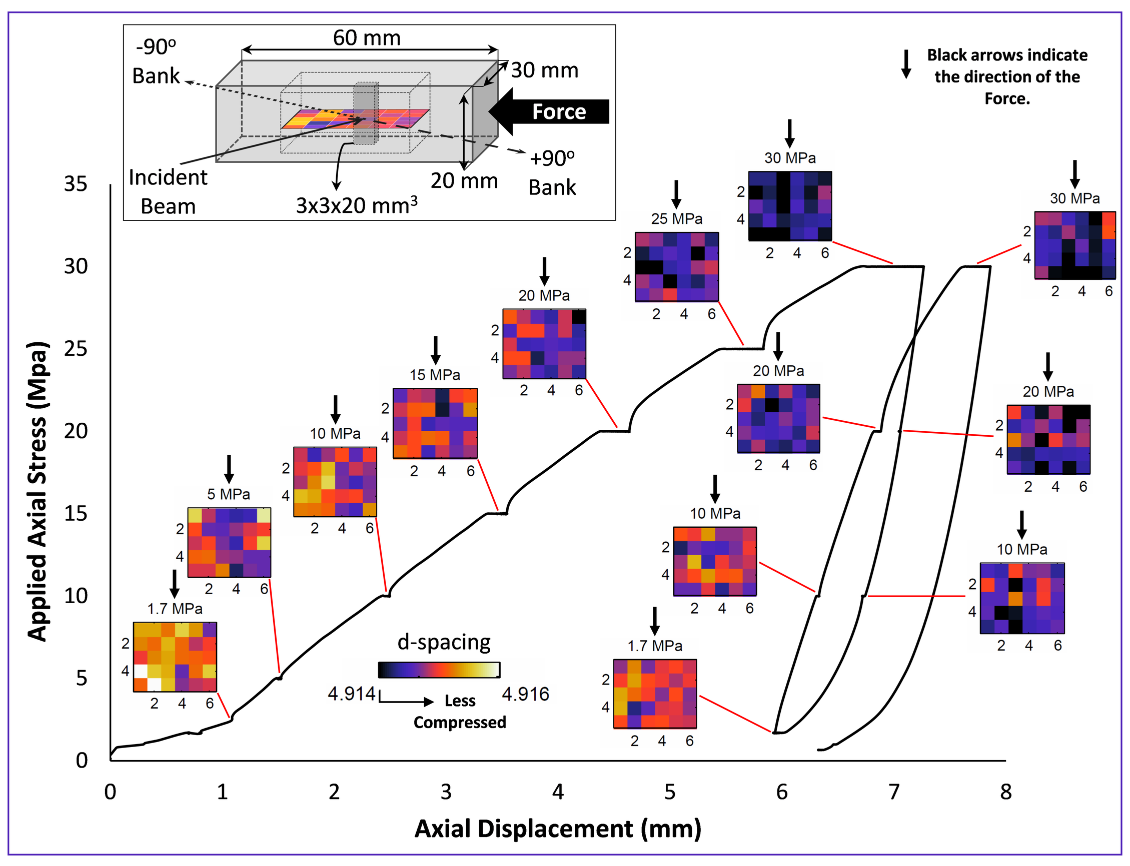

Figure 3. Macroscopic axial displacement as a function of the applied axial stress. Inset: (a) measurement and loading setup and (b) 2D grain-strain mappings (white being less compressed and black being more) per load step.

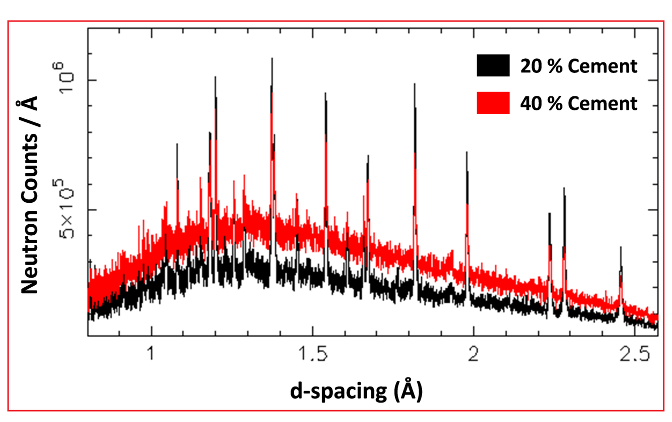

Figure 4. Neutron Diffraction d-spacing measurement on two samples with different cement percentage.

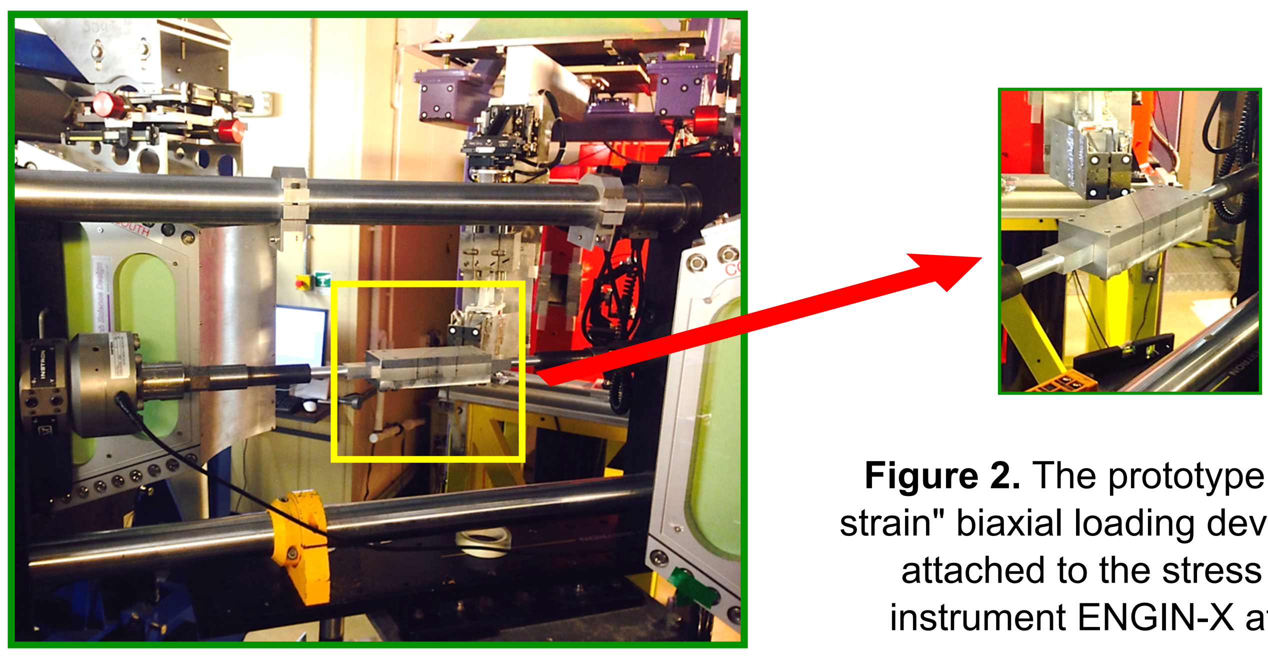

Figure 2. The prototype "plane-strain" biaxial loading device (MKI) attached to the stress rig of instrument ENGIN-X at ISIS.

Macro-Strain Curve Analysis (Fig.3):

- Almost **uniform trend up to the 1st max** load (ε_{axial} = -0.121).
- Slight **change of gradient** between **20 & 25 MPa / 25 & 30 MPa.**
- **1st unloading** follows a path of much **higher gradient** (residual ε_{axial} of about -0.1).
- **Reloading** follows **similar high gradient** (material gets stiffer).
- **After the 20 MPa** load step the **gradient decreases** again and **axial strain increases** slightly (ε_{axial} = -0.131).
- **2nd unloading** load almost in **parallel with the 1st**.

2D Grain-Strain Mappings Analysis (Fig.3 - Inset b):

- **Significant variations** at initial load steps indicate grain **re-organisation & locking** and **porosity reduction**.
- **After 20 MPa** in both loadings the **damaging process possibly starts** (mappings show a more clear pattern).
- The **residual macroscopic strain** has some **contribution** from **residual strains in the grains** and **not just porosity loss** (by comparison of the mappings of the 1st loading to those of the unloading).
- In general **results** seem to be **consistent** with the assumption that **unloading in one area leads to another area taking up the load**.

* Realisation of individual scans on **samples with different cement percentage** (Fig.4) indicated **significant incoherent background** from OPC, which **increases as the percentage of cement increases** in the sample.

Future Objectives

- **Fully operational** experiments with the **MKII apparatus** at **ISIS** (UK) and **ILL** (France) in Autumn 2015 (test experiments with MKII already realised at ILL in May 2015).
- **Design re-optimisation** and construction of the **MK III apparatus** (in collaboration with the Insitute of Petroleum Engineering of Heriot-Watt University) to achieve **higher confining pressures** (10s of MPa) and include **Ultrasonic Tomography** for the assessment of the evolution of **stiffness**.
- Construction of **prototype fluorinated membranes** to enclose **"flexible" ultrasonic transducers**.
- Testing **new types of cementation** (deuterated OPC, Gypsum-rich OPC, CAC, i.a.) to **minimise / eliminate the incoherent background**.
- Take **spatial mapping a step further** and investigate the **effect of cementation** and **cement degradation**.

References

Hall S.A. et al., 2011, Granular Matter, 13, 251-254
Wensrich C.M. et al., 2012, Granular Matter, 14, 671-680

Contact E-mail

stefanos.athanasopoulos@solid.lth.se

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