13th Australia New Zealand Conference on Geomechanics – Acosta-Martínez & Lehane (Eds.)

Design and application of a high-performance true triaxial stress cell

A. Rezagholilou, S. Fallahzadeh, N. Nourifard, S. Tehrani, N. Tarom & M. Sarmadivaleh
Curtin University, Perth, Australia

ABSTRACT: Conventional triaxial tests are for axisymmetric stress condition. In deep layers, simulation of real stress field condition requires an equipment capable of carrying high range orthotropic stress condition and pore pressure. Interaction of fluids with vertical and two horizontal stresses are important for reservoir and drilling stabilities. A new generation of high-performance True Triaxial Stress Cell (TTSC) has been built which allows orthogonal loadings. Designed TTSC allows vertical and two independent horizontal stresses to be applied up to 70 MPa on a 50x50x50 mm cube of the rock sample. Additionally, pore pressure can be up to 20 MPa and temperature up to 70^{O}C. Six sets of LVDT strain gauges and 24 acoustic transducers can monitor all deformations and cracking events occur during fracture of sample. Through a hole in the center of the rock, a fluid can be injected to simulate hydraulic fracturing, or investigate fault reactivation during fluid injection. Sanding can also be studied by varying stresses and pore pressures as well. All of events are monitored in real-time manner using ultrasonic seismic transducers around the sample. Further details of this equipment, manufactured by Curtin University, are explained in this paper

1 INTRODUCTION

In rock mechanics, estimation of the strength and deformations under various stress states which exist in ground are essential (Chang and Haimson, 2000). Conventional triaxial tests are for cylindrical samples whereas rock sample is subjected to equal confining pressure (σ_2=σ_3) with an axial stress (σ_1). This status only occurs in special case or normal stress condition. However there is often orthogonal stress condition ($\sigma_1 \neq \sigma_2 \neq \sigma_3$) in deep formations which impact well-bore or reservoir stability analysis. This condition can be due to anisotropy of rock properties, faulting and various tectonic features. Accordingly, this point implies that rock samples in laboratory investigations should be examined by a high performance True Triaxial Stress Cell (TTSC) apparatus which can replicate a real stress environment to develop the knowledge of rock mechanics effectively. This type of triaxial cells could be used for simulating various geomechanics applications including CO2 sequestration, flooding and permeability measurement, hydraulic fracturing, sanding and strength analysis. Through a hole in centre of the rock, a fluid can be injected to simulate hydraulic fracturing, or to investigate fault reactivation during CO2 injection. Sanding analysis can be performed by increasing pore pressure and producing the pore fluid through the borehole. Fracture propagation, sanding initiation, and in-flow production performance are monitored in real-time using ultrasonic seismic transducers mounted around the sample.

1.1 *Previous attempts*

Researchers at Curtin University developed the first cell of this kind in 2010 to accurately model the volatile stress environments encountered at earth in depths up to four kilometers. Figure 1 shows the general arrangement for a sample in cell which can be 100 mm to 300 mm in size. Accommodation of small samples requires spacers.

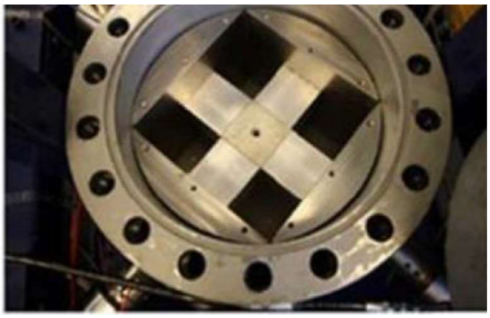

Figure 1. 300 mm TTSC cell and accessories (Sarmadivaleh, 2012)

As such, spacers can transfer the loads over samples with various sizes. However, horizontal rams (shims) and top vertical ram are responsible to apply independent horizontal and vertical stresses respectively as shown in Figure 2.

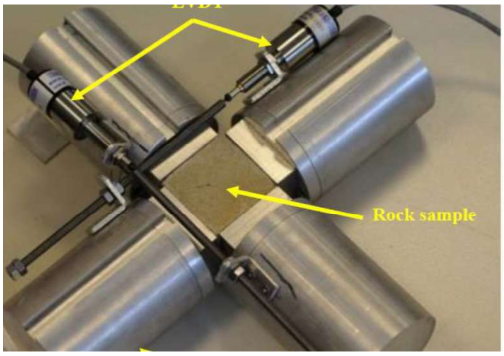

Figure 2 Interior assembly configuration (Minaeian, 2014)

Top lid facilitate positioning of top ram for vertical stress. Deformations in each direction can be recorded by Linear variable differential transducers (LVDT) attached to each ram. Sample preparation is important as rock surfaces should be cut in accurate size and be polished. These are to avoid any placing issue, distortions of loadings and /or non-uniform stresses over surfaces. Syringe or Hydraulic pumps with pressure capacity up to 103.5 MPa can be used to exert stresses over surfaces. For hydraulic fracturing, fluid injection can be either in constant flow rate with a maximum capacity of 650 cc/hr or constant pressures or any other loading patterns introduced to syringe pumps. Deflections of rams also can be up to 20 mm which is quite enough for most cases. The main capability of this facility is acoustic emission and acquisition system. This feature enable users to monitor acoustic events due to any fracture move. Induced or transmitted acoustic pulses are recoded by 16 sensors in real time manner (see Figure 3). Capture of signals in all directions make it possible to map any crack propagation and stress-induced anisotropy.

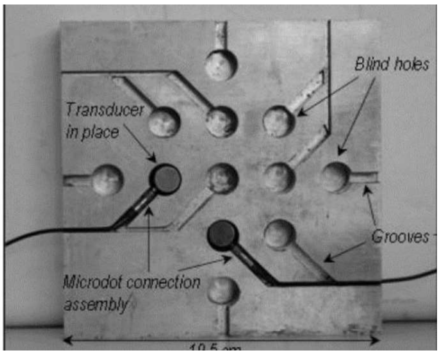

Figure 3. Designed spacers with 12 holes to host transducers (Nabipour, 2013)

2 NEW TTSC FACILITY

With support of National Geosequestration Laboratory (NGL), new equipment was manufactured by Curtin University in 2016. It was to deliver innovative solutions to carbon storages projects in Australia. This cell is for 50 mm cube samples and is a kind of pressure vessels to host fluid or gas ultra-high pressures safely.

In the most stages of this work, it was difficult to find an off-the-shelf or commercial part matching the functions required for the whole equipment arrangement. Thus the best way was to design and built something which suits needs of project.

The design and fabrication of 50 mm cell has been inspired basically by 30 cm standard TTSC built in 2010. The main difference of this new cell with the previous ones in its internal design and functionality mainly about sealing systems that are closely based on similar small cell in Brazil (unpublished) as shown in Figure 4 to 5.

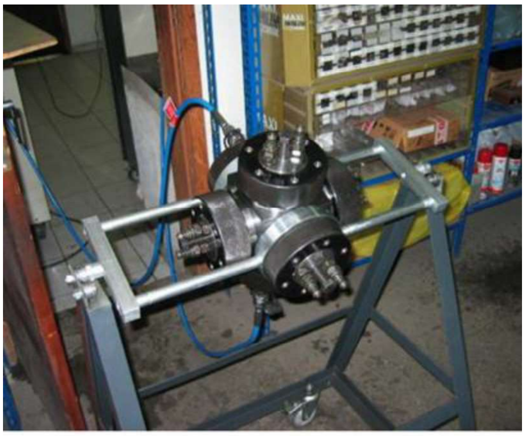

Figure 4. General configuration of Brazilian cell

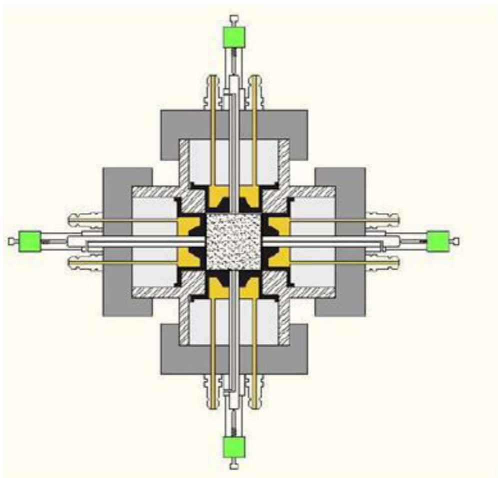

Figure 5. Internal design of Brazilian cell

Brazilian cell can hold pressures or stresses up to 120 MPa. It has automatic computer control of pressures; displacements/strains gages at each face. There is no evidence for its injection capabilities. It can measure

permeability along the loading paths from each opposite face. Figure 5 shows how sealing system which works under compression mechanism.
This cell seems to have injection or pore pressure systems but features such as high temperature, corrosion resistance are not clear.
New cell of 50 mm cell has all above functions as well as delicate acoustic system. This cell has improved operability with reduced number of components specifically for users as shown in Figure 6. In particular, the easy assembling and stressing provisions are provided by simplified articulations. This in turn clearly lowers the associated maintenances which are a real challenge in its maintenance.

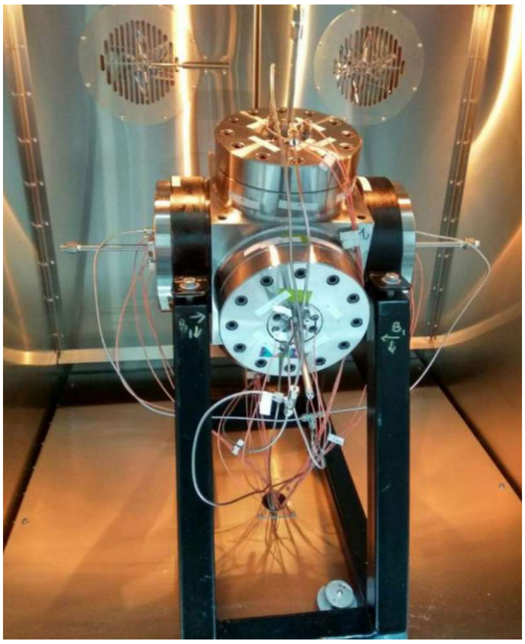

Figure 6. General configuration of 50 mm TTSC

2.1 *Cell body*

The complexity of each element's functions required highly meticulous thoughts and intelligence for verifications and innovations and feasibility evaluations. Initial drafts or conceptual design of this cell was based on sizing of acoustic transducers, connections and feedthroughs.
More importantly, broad area for crushing of Viton or Polyurethane sleeve was anticipated to avoid any fluid by-pass or leak. In addition, details of O-ring as double defense line was considered to manage any stress concentrations in cell body.
In general, the main aims during concept design was to have high degree of reliability, component standardization for reducing spare parts, and shorter test preparation. The oil chamber tried to be small similar to Figure 5 but it was dependent to size of connections as well.
Structural analyses of cell body was essential. Steel grade was 4140 because of its higher strength and availably of 70 cm steel blocks in Perth for machining purposes.

2.2 *Ultrasonic system*

This TTSC primarily is built for laboratory-based CO2 injection studies. Previous cell in 2010 included ultrasonic transducers on all six sides of rock specimen, whereas transducers being pressed by springs within recessed indentations anticipated on loading faces. Fluids can be injected into the rock which in turn cause changes in stress and lead to fractures. As the fracture tip propagates, it will cause micro seismic events to occur and eventually the fracture progress as typically shown in Figure 7.

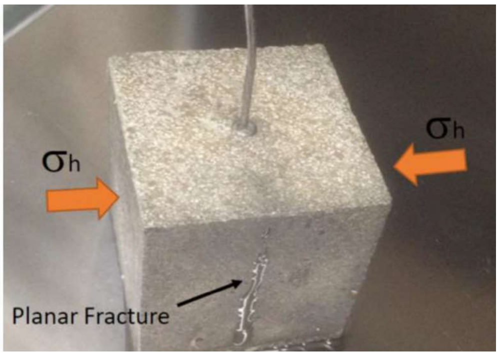

Figure 7: A planar fracture propagation after Hydraulic fracturing test

New 50 mm TTSC have 4 transducers per face, amounting to a total of 24 transducers each being sampled at every 0.1 µsec. All transducers will have the ability to record data in listen mode continuously recorded into a standard memory using software based on Labview. Once an event is observed (a peak in amplitude), the signal timing and event character (adjustable 200 µsec before the event and 300 µsec after the event) will be recorded and retained while all other data is then deleted. A knowledge of the velocity field of the block will be obtained by pulsing all transducers once with all other transducers recording, to provide a calibration database of the velocity field of the block. Using this database, a 3D location and display of each event's origin would be computed as conventionally processed in acoustic emission processing.
At a period of no longer than once per second immediately following the peak of such an event, all transducers will be pulsed in multiplexed format, using a spike from a programmable pulse generator. That is, each transducer in turn will be pulsed and fired into all other 24 transducers. The arriving wavelets will be recorded for 0.5 µsec from each individual pulse.
The data recording process is considered to therefore have passive and active modes of operation: The pas-

sive mode of listening for an event requires conventional acoustic emission processing to provide the physical location in 3D space of each event within the block. A database containing position of all transducers will be used to determine time-of-flight of arrivals to allow a velocity cube to be established as the base velocity calibration procedure.
The active mode allows the selection of conventional seismic reflection processing (and stacking) to occur where there appears to be an alignment of reflections. In addition, it will record tip diffraction events to dis-play, in similar mode to the Acoustic Emission (AE) process, the location of the fracture tip and also pro-cess transmission arrivals to determine arrival values of amplitude.

2.3 *Sealing elements*

This cell is a kind of pressure vessels and theoretically should be able to handle hazardous fluids or gas in ultra-high pressures. Thus shapes of sections should be preferably spherical, cylindrical, and conical as far as possible. Consequently sealing systems need to have similar shapes otherwise not-uniform pressure distribution can lead to unfavorable and uncontrollable leakages. Additionally right angles and its mouldings would be highly difficult due uneven shrinkages or entrapped air bubbles during plastic injection either in warm or cold methods. Anticipated shrinkages for polyurethane is about 1% which should be seen during internal design or sleeve moulding. Hardness of sleeve is another important factor that directly affect its ductility or movability during operations or test preparations.

In general, there are broad range of materials available for this purposes, thus it was so difficult to determine which one is appropriate for a project. However pros and cons of each material have been studied which influence sleeve function and costs in long or short term expectations.

Type of fluids and their corrosive and thermal inter-actions were also should have been seen in design. This means that numerous designing criteria could be included in material selection which end up with mixture consist of Polyurethane part A and B (polyurethane 83A, product Name ERA) plus pigments and releasing agents.

Whole cell system can be placed in controlled temperature condition by mean of advanced oven chamber as shown partially in Figure 6. This chamber also provide required safe operation and reliable functioning environment in case of any accidental failures for a pressurized vessel.

3 CONCLUSION

The new 50 mm TTSC system is being manufactured in Curtin University. This unique system can expand the knowledge of advanced geomechanics by allowing real time monitoring of cracks in rock specimens. Any particular stress regime can be implemented on real or synthetic samples. This apparatus is superior to previous generation of TTSCs and conventional cells in rock mechanics where as limited hydro-mechanical properties can be investigated

REFERENCES

Chang, C., and Haimson, B., 2000, True triaxial strength and deformability of the German Continental Deep Drilling Program (KTB) deep hole amphibolite: Journal of Geophysical Research: Solid Earth, v. 105, no. B8, p. 18999-19013.

Minaeian, V., 2014, True triaxial testing of sandstones and shales: Curtin University.

Nabipour, A., 2013, Experimental and numerical study of ultrasonic monitoring of hydraulic fracture propagation: Curtin University.

Sarmadivaleh, M., 2012, Experimental and numerical study of interaction of a pre-existing natural interface and an induced hydraulic fracture, Citeseer.