Upgrading the rock mechanics laboratory at the Nanyang Technological University, Singapore

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Abstract

To cater for the R&D activities associated with the fast-growing underground space development in Singapore, the Nanyang Technological University has spent a considerable effort in upgrading the rock mechanics laboratory for the past 5 years. The key upgrades and purchases focus on enhancing the R&D capability in the following three major areas of "preparation of rock specimens", "sampling and characterization of rock specimens", and "loading rock specimens at different conditions". This paper shares the experience of the laboratory upgrading. The key considerations of the major expensive purchases are addressed.

Keywords: Laboratory,Rock Mechanics,Experimental Study

1. Introduction

The past and the coming decades see an exciting opportunity of rock engineering research in association with the fast-growing underground space development in Singapore. The successful construction and commissioning of the Underground Ammunition Facility by the Ministry of Defense in 2008 and the Jurong Rock Cavern (Phase 1) for the storage of hydrocarbon by the JTC in 2014 signify the importance of underground space resource in this country. To support such engineering activities, the local universities, especially Nanyang Technological University (NTU), have been actively conducting relevant engineering geology and rock engineering research. As such, a considerable effort has been spent in upgrading the rock mechanics laboratory for the past five years. The key upgrades and purchases focus on enhancing the R&D capability in the following three major areas, namely "preparation of rock specimens", "sampling and characterization of rock specimens", and "loading rock specimens at different conditions". This paper summarizes the experience of the laboratory upgrading.

2. Preparation of rock specimens

Rock samples are retrieved from the sites typically either in the form of rock cores or rock blocks. The former are obtained by rotary coring method, while the latter are obtained from cavern/tunnel excavation using the drill-and-blast method. Rock specimens are then prepared in general accordance with the ISRM suggested methods and/or ASTM by cutting them into appropriate dimensions, which are then grinded smooth. Cutting is performed on a circular cutting saw (Fig. 1) or a linear precision cutting saw (Fig. 2). The grinding and polishing of rock specimens is performed on an automatic surface grinding machine (Fig. 3). For grinding and polishing small specimens, the equipment as shown in Fig. 4 is used.

Fig. 1. Circular cutting saw

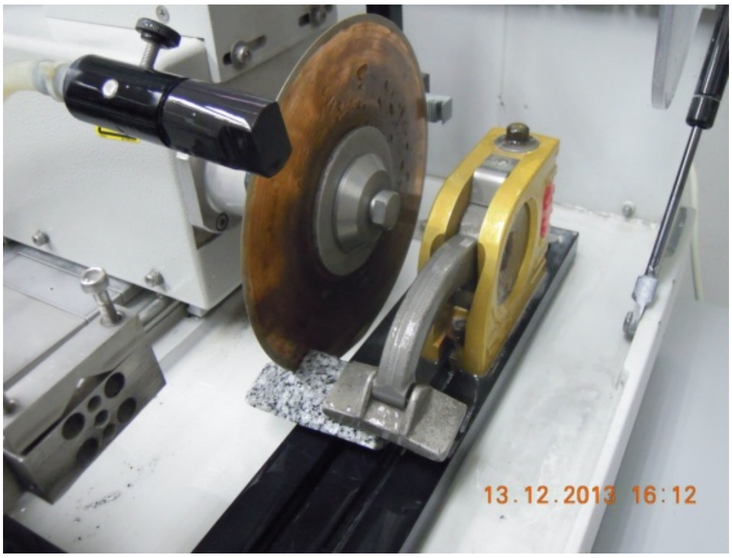

Fig. 2. Linear precision cutting saw

Fig. 3.Automatic surface grinding machine

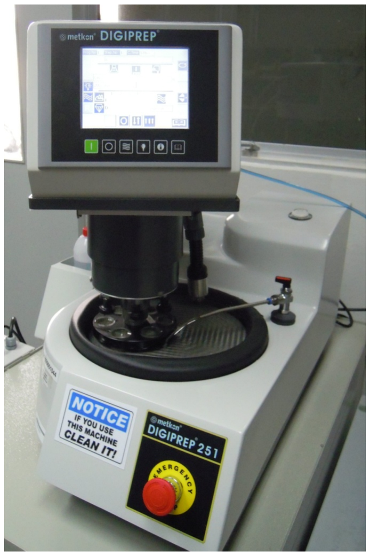

Fig. 4.Automatic sample grinding and polishing system

To cut specimens in non-standard dimensions and shapes, the OMAX 2626Precision JetMachining Center is used. It is able to cut complex workpieces from virtually any material with a high precision and speed. The operation of the abrasive jet is highly computerized (Fig. 5). Cutting is achieved by ejecting a high-speed stream of garnet abrasive-laden water at a speed of about 100 feet per second from a jet nozzle onto the rocksto be cut (Fig. 6). The garnet grains have a size of 75 µm. The extremely high erosive power of water stream is able to create straight flaws of rounded tips within tens of seconds for experimental studies of crack initiation and propagation in rock specimens containing artificial cracks.

Fig. 5. OMAX 2626 Precision JetMachining Center

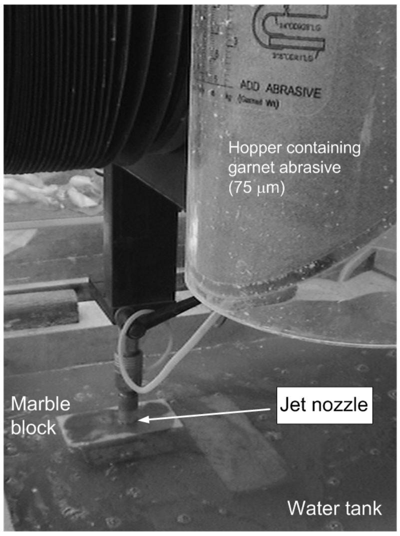

Fig.6a. Close-up view of the jet nozzle

3. Sampling and characterization of rock specimens

This section describes the equipment catering for studying the rock properties or observing the rock deformation during loading tests. Petrographical polarizing microscope (Fig. 6a) is used for the identification of minerals and microstructures in rocks. The model we purchased is Nikon Eclipse LV100N polarizing microscope. The specimens can be viewed either at normal light or ultra-violet radiation. Micro-cracks which are filled with epoxy mixture are invisible under normal light, but become illuminating under ultra-violet radiation due to the presence of fluorescent dye (Fig. 7). The microscope is equipped with five different objective lenses of magnifications 4x, 10x, 20x, 40x and 100x. A digital camera (Nikon Digital Sight DS-U3) mounted to the microscope port records images of the observed scene on a light-sensitive sensor, and transfers them to the computer. The software NIS-Elements 4.1 acquires a live stream of image data from the camera to the computer in real time. This enables live visualization of microscopic observations on the computer monitor. The software allows a direct measurement of the dimensions of the target objects, e.g. crack length. The software can also stitch adjacent images together to provide a larger view of the surface.

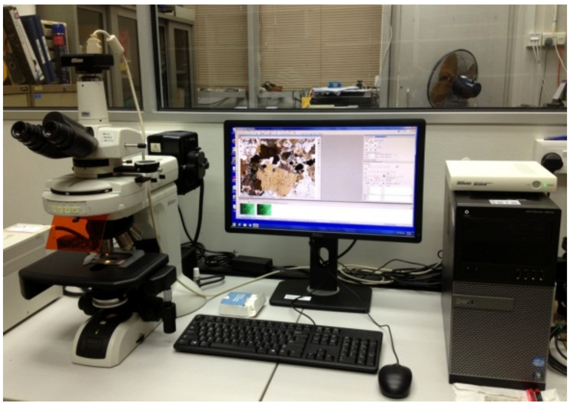

Fig. 6b. Petrographical polarizing microscope

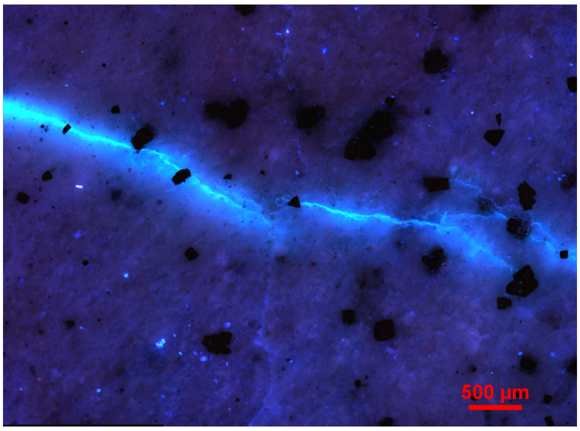

Fig. 7. Microscopic image of a crack filled with epoxy-dye mixture observed under ultra-violet light condition

Phantom V310 high speed camera (Fig. 8) is used to capture the dynamic performance, particularly crack initiation, propagation and coalescence, of rock materials under loading. Images are continuously fed into the camera and stored in its 16 Gb internal memory. Unless the camera is triggered, the earliest-captured images are continuously discarded. In order to store the images permanently, the user needs to Trigger the camera. The highest resolution of 1280×800 pixels is captured at 3250 frames per second (FPS), while a maximum frame rate of 500,000 FPS can be captured at a resolution of 128×8 pixels. A Cool Light Kit provides a continuous illumination without worrying the heat.

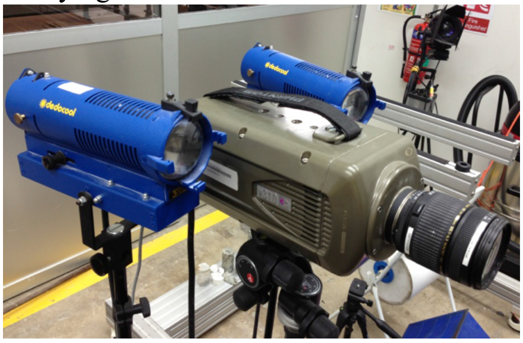

Fig. 8. High speed camera

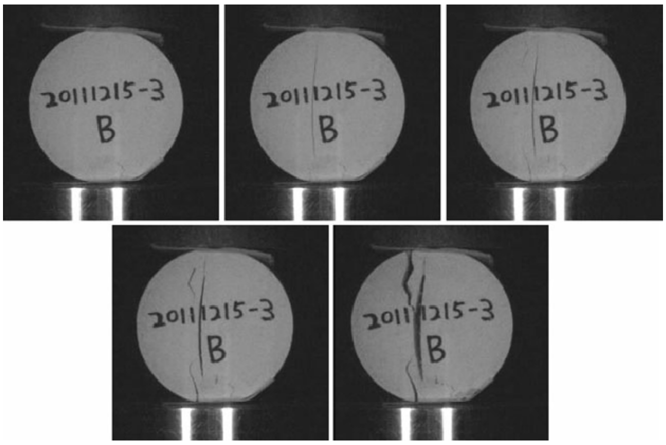

Fig. 9. Snapshots of a high speed video showingthe primary crack initiating atthe center of the gypsum specimenfollowed by the development ofseveral secondary cracks in a Brazilian tensile disc test.

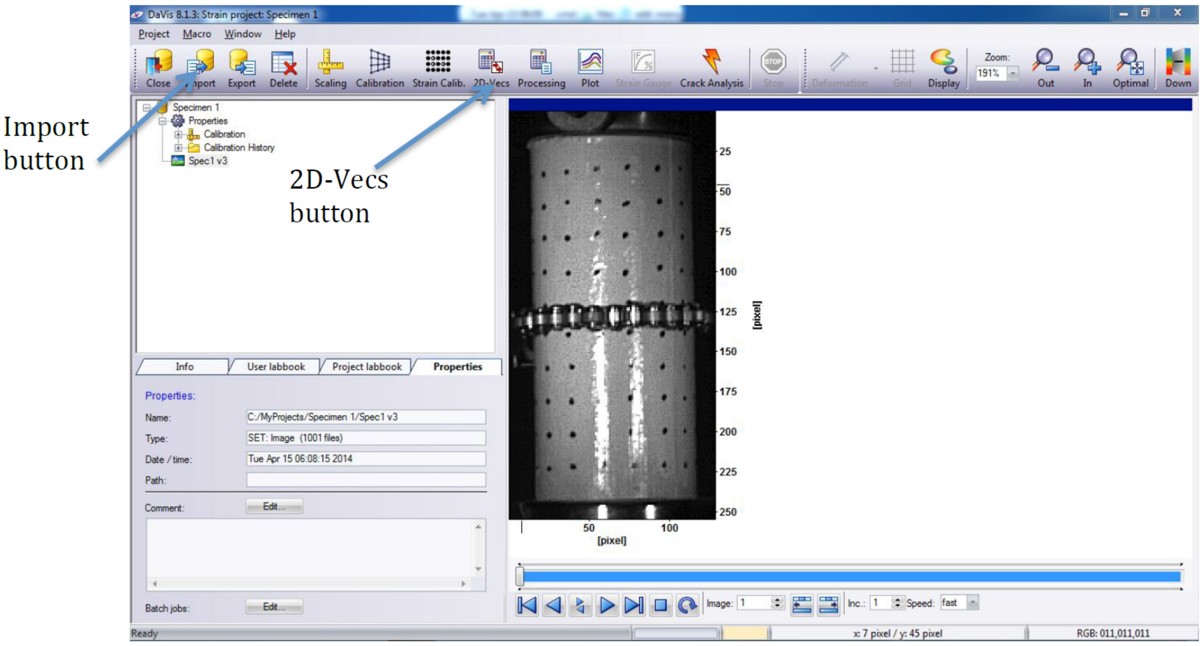

Fig.10. Using StrainMaster to capture the deformation of a cylindrical specimen under vertical loading.

To assist the monitoring of the specimen under loading, a digitalimage correlation (DIC) softwarecalled **StrainMaster**developed by LaVisionis used (Fig. 10). It is a non-intrusive optical tool for shape, strain and deformation analysis of solid, granular and liquid subjects.A series of images are first acquired from a rock mechanics test, with the first image normally being the case of zero applied load. After the suitability of the natural or applied pattern has been assessed, the measurement and analysis can take place. The displacement of the surface pattern between successive images is calculated by an advanced grey scale analysis.

Multichannel acoustic emission (AE) system of the model Micro-II Samos 16 manufactured by Physical Acoustics Group was purchased recently (Fig. 11). It contains a compact AE system chassis forholding up to four PCI-8 AE system cards with AE LED's, integrated CPU & Ethernet connection. Each PII-8 card can accommodate 8 AE channels. The AE system will be used to pick up signals to locate the microcracking events during the loading experiments on rocks.

Fig. 11. Multichannel acoustic emission (AE) system running with monitor &keyboard/mouse (http://www.pacndt.com/index.aspx?go=products&focus=/multichannel/Micro-II.htm)

4. Loading rock specimens at different conditions

To model different loading conditions, different loading rigs and set-ups have been purchased or upgraded. An existing direct shear test set-up has been reinstated by substituting the control unit and hydraulic pump (Fig. 12). The SCON-1500 universal digital signal conditioning and control unit features an integrated 850 MHz microprocessor based digital servo controller and includes the CATS Standard software. This is a complete and self-contained module featuring built in function generator, data acquisition, and digital I/O unit. It can accept load cells, pressure transducers, LVDTs, or other analog input signals. The CATS Standard software allows the user to create a variety of wave forms. The standard system also includes calculated inputs from one or several analog channels that can be directly servo controlled or monitored in real time.

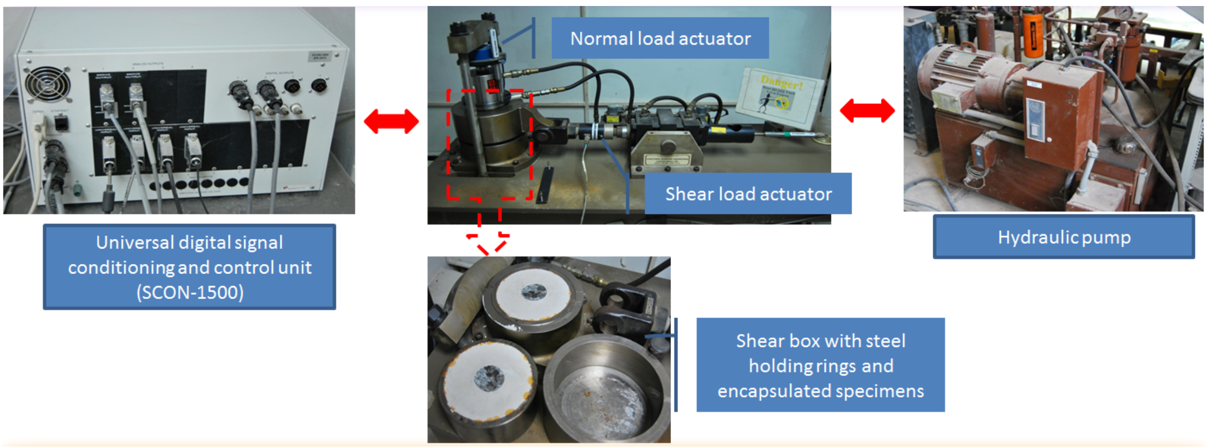

Fig. 12. Upgrading of the direct shear test setup.

The most important and expensive purchase is the MTS 815 Test System (Fig. 13). It offers a high axial force capacity, with compression ratings up to 4600 kN and tension ratings up to 2300 kN.Its highly stiff load frame, fixed crossheads and single-ended actuators make this system suitable for the study of the post-failure behavior as well. It has a 100 mm (4 in.) stroke for tests requiring large displacements.The frame assembly includes two feedback transducers – a differential pressure (ΔP) transducer and an internal linear variable differential transformer (LVDT) that provides control and measurement of actuator displacement. The system comes along with the MTS Geomechanics Application Software, which provides a set of test templates that follow standard test sequences and analyses described by ASTM and ISRM. The present purchase also includes a number of accessories to cater for compression, strain measurement, circumferential strain measurement, indirect tension(Brazilian tensile disc test), direct tension and fracture toughness.

Fig. 13. MTS uniaxial loading frame

Fig. 14. Conducting a mode-I fracture toughness test

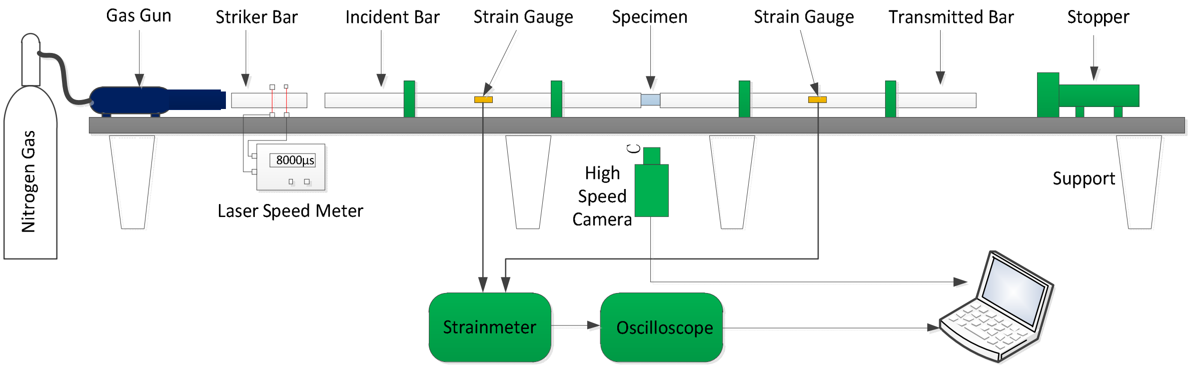

Fig. 15. Split Hopkinson Pressure Bar (SHPB) setup

The Split Hopkinson Pressure Bar (SHPB) setup (Fig. 15) is used for rock dynamics study. An impact force is produced the incident bar due to the impact of a striker bar. The waves traveling in the incident bar and transmitter bars are monitored and recorded by strain gauges, strain amplifier and oscilloscope. Based on the stress wave propagation theory, the dynamic stress-strain relations of the rock specimen between the two bars can be calculated. Apart from the high speed camera as mentioned in section 3 for the observation of cracking details, two key upgrades of strainmeter and oscilloscope related to data capture and storage in SHPB tests are described below..

The high frequency strainmeter is a key component of the SHPB system for capturing the strain data. TML wide-band direct-current dynamic strainmeter, DC-97A, manufactured by Tokyo Sokki Kenkyujo Co., Ltd. Japan (as shown in Fig. 16a) is used for the present SHPB tests. The DC-97A strainmeter with the high frequency response and superblinearity satisfies the demand for measuring impact strain. There is no need for capacity balancing. Both constant voltage and constant current are allowed due to the bridge power supply system. One DC-97A module is one measuring channel. Eight DC-97A modules have been united together in one case to create a multi-channel system (Fig. 16b).

(a) (b)

Fig. 16. (a) TML dynamic strainmeter unit – DC-97A (www.tml.jp), (b) The eight-channel strainmeter system

The existing oscilloscope (digital scope) has been upgraded to the Yokogawa DL850digital scope (Fig. 17), which has a sample rate of 10 MS/s to 100 MS/s. It is used to record the data amplified by the strainmeter obtained in the SHPB test.

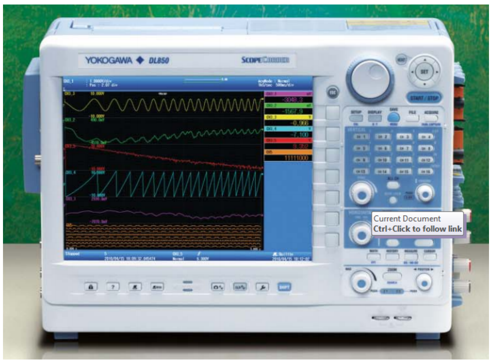

Fig. 17.Yokogawa DL850digital scope

(http://tmi.yokogawa.com/sg/discontinued-products/oscilloscopes/scopecorders/dl850dl850v-scopecorder/).

5. Conclusions

Due to the keen interest of underground space development in Singapore, NTU has ungraded the rock mechanics laboratory in various aspects to cater for the relevant rock mechanics experimental research. This paper describes some of the key purchases and upgrades over the past 5 years. Some research results have been successfully obtained and published. More research output is encouragingly expected in the near future.

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