Journal of Rock Mechanics and Geotechnical Engineering 9 (2017) 599–610

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

Specimen aspect ratio and progressive field strain development of sandstone under uniaxial compression by three-dimensional digital image correlation

H. Munoz [a,b,*], A. Taheri [b]

[a] Deep Exploration Technologies Cooperative Research Centre (DET CRC), Export Park, Adelaide Airport, Adelaide, SA 5950, Australia
[b] School of Civil, Environmental & Mining Engineering, The University of Adelaide, Adelaide, SA 5005, Australia

ARTICLE INFO

Article history:
Received 5 September 2016
Received in revised form
25 January 2017
Accepted 28 January 2017
Available online 10 July 2017

Keywords:
Uniaxial compression test
Aspect ratio
Strain patterns
Digital image correlation (DIC)

ABSTRACT

The complete stress–strain characteristics of sandstone specimens were investigated in a series of quasi-static monotonic uniaxial compression tests. Strain patterns development during pre- and post-peak behaviours in specimens with different aspect ratios was also examined. Peak stress, post-peak portion of stress–strain, brittleness, characteristics of progressive localisation and field strain patterns development were affected at different extents by specimen aspect ratio. Strain patterns of the rocks were obtained by applying three-dimensional (3D) digital image correlation (DIC) technique. Unlike conventional strain measurement using strain gauges attached to specimen, 3D DIC allowed not only measuring large strains, but more importantly, mapping the development of field strain throughout the compression test, i.e. in pre- and post-peak regimes. Field strain development in the surface of rock specimen suggests that strain starts localising progressively and develops at a lower rate in pre-peak regime. However, in post-peak regime, strains increase at different rates as local deformations take place at different extents in the vicinity and outside the localised zone. The extent of localised strains together with the rate of strain localisation is associated with the increase in rate of strength degradation. Strain localisation and local inelastic unloading outside the localised zone both feature post-peak regime.
© 2017 Institute of Rock and Soil Mechanics, Chinese Academy of Sciences. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

The characterisation of post-peak behaviour associated with the decrease of rock load-bearing capacity, crack development as well as rock brittleness is critical to many civil engineering applications, mining development projects, and mineral exploration operations. The complete stress–strain characteristics of intact rock, i.e. pre- and post-peak regimes, picture the total process of rock deformation and failure behaviour. Pioneering studies on the complete stress–strain behaviour of rocks undergoing quasi-static compression basically classify rocks into two categories (Wawersik and Fairhurst, 1970; Hudson et al., 1971; Wawersik and Brace, 1971; Fairhurst and Hudson, 1999): class I, which is characterised by a negative post-peak slope, where fracture propagation is controllable by a rigid axial-displacement controlled machine, and class II, showing positive post-peak slope, where fracture propagation is uncontrollable using the same testing arrangement. The failure mechanism of brittle rocks generally has a noticeable display of abrupt post-peak drop in stress immediately after the peak strength takes place towards the residual strength, if any, on the characteristic stress–strain curve (Wawersik and Fairhurst, 1970; Wawersik and Brace, 1971; Martin and Chandler, 1994). The determination of this abrupt drop of stress has been a key issue relevant to a number of geotechnical engineering applications, including for instance unstable behaviour analysis of brittle-plastic rock mass in large rock excavations, and it has been approached by extending the classical theory of plasticity to modelling brittle-plastic materials (Zheng et al., 2005).

Rock behaviour under axial loading is generally studied in laboratory using load- or displacement-controlled compressive loading systems. Load-controlled method, however, can only measure pre-peak behaviour. A common method to control axial load is to use axial displacement (or axial strain) rate feedback in servo-controlled compressive machines (Bieniawski and Bernede,

* Corresponding author.
E-mail address: henry.munozprincipe@adelaide.edu.au (H. Munoz).
Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

http://dx.doi.org/10.1016/j.jrmge.2017.01.005
1674-7755 © 2017 Institute of Rock and Soil Mechanics, Chinese Academy of Sciences. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1979). To measure the post-peak behaviour of rocks, this method has been used in unconfined and confined conditions (e.g. Gowd and Rummel, 1980; Taheri and Tani, 2008; Kumar et al., 2010; Taheri et al., 2016). Nevertheless, axial strain feedback is insufficient to measure post-peak regime for class II rocks. This is because axial strain in the compression tests no longer increases monotonically from the moment rock starts behaving as class II (Munoz et al., 2016a). As a result, using axial-strain feedback method, a critical response on the rock stress–strain curve takes place, suggesting rock drastic failure. Consequently, post-peak stress–strain behaviour is masked by a rapid strength reduction at constant axial displacement immediately after peak stress (e.g. Labuz and Biolzi, 2007). However, this post-peak critical response may be a manifestation of axial displacement-controlled machine compliance, but not material behaviour. Circumferential- or lateral-strain controlled method, however, is suggested to measure post-peak stress–strain for brittle rocks. This is mainly because lateral displacement monotonically increases after the peak stress even if axial displacement decreases (Munoz et al., 2016a).

Not only the proper application and correct measurement of load, but also the proper measurement of deformations and strains in the specimen are crucial to obtain features of stress–strain in pre- and post-peak regimes. The latter can be accomplished by instant deformations of the material provided by a series of digital images. Digital image correlation (DIC) technique refers to the class of non-contact deformation and motion measurement method, recording simultaneous image points of undeformed and deformed states of an object (Sutton et al., 2009). Two-dimensional (2D) DIC has been previously employed in material deformation measurement under predominantly in-plane displacements and strains conditions (Dautriat et al., 2011; Nguyen et al., 2011). However, 2D DIC is impractical to be applied to cylindrical specimens in uniaxial compression as relatively small out-of-plane motions introduce errors in the measurement of in-plane displacements. Three-dimensional (3D) DIC solves the limitations of 2D DIC as 3D DIC method allows full-field 3D shape and displacement measurements.

There are few investigations on the field strain pattern development of rocks under uniaxial compression in pre- or post-peak regimes using 3D DIC technique. Therefore, non-contact strain measurement via 3D DIC becomes relevant to measuring the field of strains development in post-peak regime. In addition, this technique has rarely been implemented to study effect of specimen aspect ratio (i.e. length to diameter ratio) on rock strain pattern development in pre- and post-peak regimes during uniaxial compression.

2. Experimental study

A series of uniaxial compression tests was carried out on Hawkesbury sandstone. Compression tests complied with lateral-strain controlled method in order to obtain the post-peak behaviour of rock. To study the aspect ratio and its effect on the development of strain patterns, together with pre- and post-peak stress–strain characteristics, a number of rock specimens were tested herein, having aspect ratios of 1.5, 2.4 and 3.5.

Sections below describe in detail the steps for rock preparation and instrumentation, the application of 3D DIC technique to measure deformation, and the lateral-strain controlled loading method. Features and limitations of other loading control methods, including axial-strain and axial-load, are discussed in Section 3.

2.1. Rock material and preparation

Hawkesbury sandstone is an early Middle Triassic rock abundant in New South Wales, Australia. Hawkesbury sandstone is fine-grained and has a dry density of 2260 kg/m^3.

The rock was quarried and then prepared into blocks. Later the blocks were cored for cylindrical specimens. The diameter of specimens was 42 mm. A visual inspection showed that the specimens diameter was from 10 to more than 20 times larger than the rock grains size recommended by the International Society for Rock Mechanics (ISRM) (Bieniawski and Bernede, 1979; Fairhurst and Hudson, 1999). The end faces and sides of the specimen were prepared smooth and straight according to the ISRM standard (ISRM, 1981; Fairhurst and Hudson, 1999).

2.2. Rock instrumentation

Axial deformation of the specimens was measured externally by a pair of axial linear variable displacement transducers (LVDTs) mounted on both left and right sides of specimen. Axial strains ε_A were calculated from the LVDTs readings. In addition, the rock specimen was instrumented with a direct-contact lateral extensometer (i.e. lateral ring-shaped extensometer) which was wrapped around the cylindrical specimen. This device was essential to control the axial load by lateral strain feedback. Fig. 1 shows the arrangement of LVDTs and lateral extensometer in a rock specimen.

The lateral extensometer was mounted at the mid-length of the specimens so that end-edge friction effects (Hawkes and Mellor, 1970) of confined zones due to boundary conditions (van Vliet and van Mier, 1995) on the measurements were eliminated. Lateral strains ε_L were calculated from the change in diameter of specimen induced by axial load. The lateral extensometer type used in the tests was 632.12F20-series manufactured by MTS Systems Co.

2.3. 3D DIC method

Typical testing using 2D DIC requires predominantly in-plane displacements and strains, assuming that the specimen is planar and deformation is within the object plane. 2D DIC technique encompasses the use of a single digital camera positioned opposite to the surface of the specimen. Since in-plane motions are assumed to occur in two dimensions, calibration is performed with planar motions. 2D DIC results are impractical to be applied to rock cylinders in uniaxial compression, since, in this particular case, in-plane motions are no longer applicable to curved surfaces.

3D DIC solves the limitations of 2D DIC. 3D DIC technique encompasses the use of two digital cameras positioned in a manner that ensures the surface of the specimen to be viewed from two different angles, which allows full-field 3D shape and displacement measurements (i.e. recovering the 3D position).

The aforementioned can be explained by Fig. 2 (Sutton et al., 2009). In this figure, by using a single camera, two 3D points Q and R are imaged onto a single image point p, which demonstrates that the image point p corresponds to infinite 3D points. In contrast, by using two cameras to record the image points of the same object simultaneously, a unique 3D point Q corresponds to image points (p, q'). Similarly, the image point (p, r') corresponds to a unique 3D point R.

Rock surface deformations induced by the compressive load throughout the tests were captured by taking a significant number of images of the speckle surface of the specimens by using a couple of digital cameras (i.e. Fujinon HF75SA-1, 1:1.8/75 mm, 5 megapixels resolution) suitable for quasi-static loading tests. The speckle pattern on the rocks was created by first spraying ordinary white paint and then by tarnishing black paint.

The speckle pattern was non-repetitive, isotropic and high in contrast, i.e. random pattern exhibiting no bias to an orientation and showing dark black and bright white, which were adequate in size for high strain resolution (Sutton et al., 2009). Prior to the

Download English Version:

https://daneshyari.com/en/article/4923725

Download Persian Version:

https://daneshyari.com/article/4923725

Daneshyari.com