



Contents lists available at ScienceDirect

International Journal of
Rock Mechanics & Mining Sciencesjournal homepage: www.elsevier.com/locate/ijrmms*In situ* measurements of rock mass deformability using fiber Bragg grating strain gaugesJoAnn R. Gage^{a,*}, Herbert F. Wang^a, Dante Fratta^b, Alan L. Turner^{c,2}^a Department of Geoscience, University of Wisconsin–Madison, 1215 W. Dayton St., Madison, WI 53706, USA^b Department of Civil and Environmental Engineering, Geological Engineering Program, University of Wisconsin–Madison, 1415 Engineering Drive, Madison, WI 53706, USA^c Micron Optics Inc., 1852 Century Place NE, Atlanta, GA 30345, USA

ARTICLE INFO

Article history:

Received 1 April 2013

Received in revised form

22 July 2014

Accepted 25 July 2014

Available online 7 September 2014

Keywords:

Fiber Bragg grating

Strain gauges

In situ strain

Modulus of deformation

Rock strain strips

ABSTRACT

In order to examine how the mechanical properties of a rock mass vary from the centimeter to meter scale, we performed two field point-loading tests (89 kN and 890 kN) to determine the *in situ* modulus of deformation of a rock mass. The experimental setup is analogous to plate jacking-type tests, but instead, using a point load. The experiments were done in the Poorman formation on the 4100 level (~1250 m underground) of the Sanford Underground Research Facility (SURF) at the site of the former Homestake gold mine in Lead, SD. For comparison with *in situ* values, we also conducted laboratory mechanical tests and used two geotechnical classification systems to evaluate rock stiffness. The *in situ* modulus of deformation increases with depth into the rock mass. This increase in stiffness is a result of the differences in mechanical properties due to the effect of excavation of the underground space. Near the surface (0–1.2 m depth), the rock is softest due to induced fractures and damage from blasting. Beyond this damaged zone is the stress-relief zone (1.2–1.5 m depth), where open joint sets affect rock stiffness, and beyond that lies the undisturbed zone (>1.5 m depth) where the rock is the stiffest. If done properly, *in situ* measurements of rock stiffness are a valuable tool to fully characterize the gradient in stiffness of a rock mass, which laboratory tests or geotechnical classification systems do not fully capture.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Deformability and strength are the most important geotechnical variables used to predict the behavior of a rock mass in response to loading or construction. The modulus of deformation (E_m) is one of the parameters that represents the mechanical behavior of a rock mass. However, there is no clear consensus on the most accurate method to determine a representative modulus of deformation. There has been significant work done on this problem using three main approaches: (1) extrapolation of laboratory mechanical tests to the field scale, (2) development of geotechnical classification systems that incorporate laboratory results and field observations, and (3) *in situ* measurements of rock mass deformability.

The results of laboratory mechanical tests frequently cannot be used to predict the behavior of an intact rock mass. Small laboratory samples cannot capture the effect of structural heterogeneities, such

as joints and fractures, on the mechanical behavior of a larger-scale rock mass [1,2]. In addition to using laboratory measurements, several authors have also used geotechnical classification systems to predict rock mass deformability. These classification systems incorporate field observations with the laboratory-measured rock moduli. The three main classification systems are the rock mass rating (RMR) [3], the tunneling quality index (Q) [4], and the geological strength index (GSI) [5].

Instead of using indirect classification systems or extrapolating laboratory results, it would be preferable to measure the deformability of a rock mass directly, in the field. However, *in situ* deformation measurements are time consuming, expensive, and often produce inconsistent results. The reliability and accuracy of *in situ* measurements largely depend on the experimental methods [6–8]. There are three standard tests commonly used to measure the *in situ* deformation modulus; they are the plate-loading test (PLT), plate-jacking test (PJT) and Goodman jack test [8].

The Goodman jack test is the least reliable when compared to the PLT and PJT [9] primarily because of complications associated with accurately measuring the displacement of the jack's plates and modeling the applied stress field [10]. Furthermore, Goodman jack test results typically show significant scatter because only a

* Corresponding author. Tel.: +1 832 854 5638.

E-mail address: jgage@chevron.com (J.R. Gage).¹ Currently at Chevron Energy Technology Company, 1500 Louisiana St., Houston, TX 77002, USA.² Currently at Lloyd's Register Drilling Integrity Services Inc. 1330 Enclave Pkwy, Houston, TX 77077, USA.

small volume of rock is deformed [11]. Plate-loading tests can also produce unreliable results because of the difficulty in accurately measuring displacement of the surface of the rock mass [12,13]. Plate-jacking tests produce the most reliable results because the embedded extensometers allow strain to be measured at depth within the rock mass and hopefully beyond any damaged zone surrounding the opening [14].

Although the database of *in situ* modulus of deformation measurements is not extensive, several authors have tried to combine the *in situ* measurements with the geotechnical classifications systems. Both the RMR and GSI systems can be linked to *in situ* measurements with reasonable reliability [8,15]. Other authors suggest that it is important to integrate field observations of joints, weathering and general rock mass character with any geotechnical classification scheme and *in situ* measurements [6,16,17]. Without a well-defined and agreed upon method to predict the behavior of a rock mass during deformation, it is important to critically assess both experimental methods and classification techniques and continue to examine how the mechanical properties of rock vary over spatial scales.

In this paper we present the results of two point-loading tests performed ~1250 m underground in a quartz and mica-rich amphibolite. We applied both a 89 kN (10 t) and 890 kN (100 t) point load to the rock surface, and utilized a dense array of fiber-optic strain gauges to measure strain at depth in the intact rock mass [18–20]. The resulting *in situ* moduli of deformation (E_m) are compared to laboratory measurements of Young's modulus and stiffness estimates from geotechnical classification systems, which allow us to examine how the mechanical properties of the rock vary from the centimeter to the meter scale. We also discuss several important experimental considerations to improve future *in situ* rock deformability measurements.

2. Geologic background

Our loading tests were conducted at the Sanford Underground Research Facility (SURF) at the site of the former Homestake gold mine in Lead, SD. SURF is an underground laboratory that is being built to house physics experiments and research [21]. In conjunction with the South Dakota Science and Technology Authority (SDSTA) and the Department of Energy (DOE), the Homestake gold mine is being converted to SURF. When commercial mining stopped in 2002, the Homestake gold mine was the largest and deepest (> 8000 ft.; ~2500 m) gold mine in North America.

SURF is located in the northern Black Hills of South Dakota (Fig. 1). The area was subjected to several episodes of Precambrian tectonism, resulting in metamorphism, foliation development, complex folding, shear zones, and the emplacement of dikes and veins [22]. Fluid influx during deformation and metamorphism produced economic gold deposits along the structures [23]. Uplift during the Laramide orogeny caused brittle deformation in the area of SURF [24] and created several joint sets and brittle faults. Our experiment was located in the Precambrian Poorman formation, which consists of metamorphosed tholeiitic basalt and metasedimentary rocks [25]. In the area of our experiment, the Poorman formation is a strongly foliated and lineated, amphibolite-grade mica schist that contains visible quartz, muscovite, and garnet. The Poorman formation also contains several quartz veins and vein arrays.

3. Rock mass geotechnical classification

Detailed field descriptions of the Poorman formation in the area of the experiment were completed in order to determine the

geotechnical strength classification for comparison to laboratory and *in situ* results. The Poorman formation has a well-developed foliation that is often mineralized with pyrite and chalcopyrite. The most prominent joint set (J_1) in the experiment alcove is parallel to the foliation, and its strike/dip orientation is 044/50 SE (Fig. 2). There are several sets of quartz veins from 0.2 cm to 10 cm thick that are oblique to foliation. Some of the quartz veins also have sulfide mineralization.

In addition to foliation-parallel joints, the experiment alcove contains three other joint sets (Fig. 2). The two more prominent joint sets (J_2 and J_3) are, in general, steeply dipping and cut obliquely though the alcove. J_4 is less prominent than J_1 , J_2 , and J_3 ; it is moderately dipping and oblique to foliation. J_2 is oriented 161/86 W and J_3 is 075/87 SE. The sub-vertical joint sets (J_2 and J_3) are not mineralized. J_4 is oriented 205/39 NW. The joint spacing in the Poorman formation for sets J_2 and J_3 in the alcove is 0.3 m. In general, joint aperture is less than 1 mm, and the joint surfaces are slightly rough. The rock surface is completely dry and no ground-water is observed.

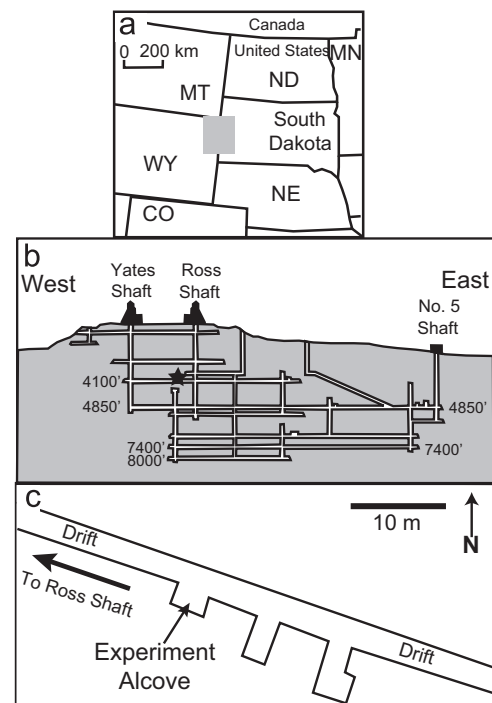


Fig. 1. Location of experiment in SURF. (a) Gray box denotes the location of the Black Hills; (b) schematic cross section of SURF. Black star denotes approximate experiment location; (c) map view of experiment alcove on the 4100 level.

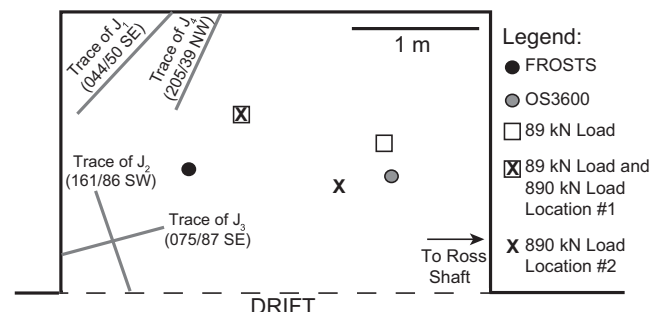


Fig. 2. Map of experiment alcove showing orientation of joint sets, location of FROSTS, embedded OS3600 sensors, and loads applied during the 89 kN and 890 kN point-loading tests.

Download English Version:

<https://daneshyari.com/en/article/7206730>

Download Persian Version:

<https://daneshyari.com/article/7206730>

[Daneshyari.com](https://daneshyari.com)