Engineering Geology 197 (2015) 103–111

Contents lists available at ScienceDirect

Engineering Geology

journal homepage: www.elsevier.com/locate/enggeo

Empirical estimation of strength of jointed rocks traversed by rock bolts based on experimental observation

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ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form 6 June 2015
Accepted 8 August 2015
Available online 12 August 2015

Keywords:
Jointed rock
Rock bolt
Uniaxial compression
Deere–Miller chart
Critical strain
Back analysis

ABSTRACT

Engineering behaviour of jointed rocks is substantially incompetent as compared to intact rocks due to the presence of joints. Rock bolts are routinely used to reinforce jointed rocks at project sites. The assessment of the strength behaviour of bolt-reinforced jointed rock is a challenging task due to the complex interaction between the joints and the bolts. The present paper attempts to resolve this issue through an experimental study. Natural rock cores with a natural joint, and synthetic rock cores with smooth joint have been tested under uniaxial compression. The tests have been performed on specimens without and with bolt. Grouted steel bolt was used to reinforce the rock. Results from the tests indicate that the provision of the bolt alters the failure mode of jointed rock, and enhances the strength and modulus values. Strength and modulus of the reinforced rock were found to be correlated with each other. It is proposed that the strength of reinforced rock can be obtained from strength and modulus of the intact rock and the modulus of the reinforced rock. The intact rock strength and modulus may be obtained from laboratory tests and the modulus of the reinforced rock may be obtained by back analysing the deformations observed in the field. Sakurai's critical strain concept has been analysed and it is observed that the correlations suggested through proposed empirical approach closely commensurate with critical strain approach and hence give scale free results.

1. Introduction

Geologists and engineers working in the field of civil and mining engineering quite often need to design structures that are situated in/on jointed rocks. Assessment of strength behaviour of such rocks, subjected to the given stress field, is a difficult task. Available solution to solve this problem is to assess the uniaxial compressive strength (UCS) of the jointed rock, and then consider the effect of the confinement through an appropriate strength criterion (Ramamurthy, 1993: Ramamurthy and Arora, 1994: Singh and Singh, 2012). The UCS, therefore, becomes a starting point in the process of analysing strength behaviour of jointed rocks. In many situations, rock bolts are used to improve properties of the jointed rocks. It is envisaged that provision of rock bolts would bring strength enhancement in the jointed rock. If an accurate estimation of the UCS of the jointed rock reinforced with rock bolts could be made, the UCS can serve well as a starting point for analysis of the reinforced rocks. Several studies have been conducted in the past to find out the parameters, which influence the strength of the reinforced rocks. Studies conducted by Dight (1982), Egger and Zabuski (1991), Pellet and Egger (1996), McHugh and Signer (1999), and Sakurai (2010) have indicated that the strength of reinforced jointed rock depends upon the strength of parent intact rock. Further, the orientation of the joints with respect to the bolt direction has also been found to influence the strength of reinforced rock (Bjurstrom, 1974; Haas, 1976, 1981; Ludvig, 1983; Pellet and Egger, 1996; Grasselli et al., 1999; and Grasselli, 2005). In addition, the mechanical properties of the bolt (Ferrero, 1995; Ferrero et al., 1997) and the grout (Villaescusa et al., 2008) also contribute to the strength of reinforced rock. The present study attempts to develop an empirical approach to assess strength of jointed rocks reinforced with fully grouted passive bolts. Uniaxial compression tests have been conducted on natural and synthetic rocks, and the results have been analysed to propose a model. The details of the experimental study are presented in the following sections.

2. Experimental programme

Uniaxial compression tests have been conducted on intact, unreinforced jointed and reinforced jointed specimens of natural and synthetic rocks. The details are as given below.

2.1. Natural rock cores (NRC)

Natural rock cores of NX size were retrieved from a project site in Garhwal region of the Indian Himalayas. The rock exposed at the site

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http://dx.doi.org/10.1016/j.enggeo.2015.08.004
0013-7952/

is gneiss with bands of quartzite and schist. The height to diameter ratio of prepared specimens was about two (diameter = 54.2 mm and height = 108.4 mm). The jointed specimens have a joint orientated at an angle varying from 0° to 90° with respect to the base of the specimens (Fig. 1a). For preparing reinforced specimens, a 6 mm diameter hole was drilled through the specimen, and a 4 mm diameter bolt was installed (Fig. 1b). No pretensioning was done to the bolt. The bolt was grouted with cement–sand mortar. The grout consists of cement, fine sand and water having ratio 2:2:1 by weight. The tensile strength of the bolts used is 550 MPa.

2.2. Synthetic rock (prismatic specimens)

Concrete was used as a synthetic rock. Two different grades (T2 and T3) of concrete were used to cover a wide range of strength. The constituents of these grades are given in Table 1. The size of the intact and jointed specimens was 150 mm × 150 mm × 300 mm (height). The specimens were prepared by casting concrete through moulds, which were especially designed for the study. For preparing jointed specimens, a thin steel plate was placed in the mould to separate the two halves of the specimen. The prepared specimens carried one joint inclined at 0° to 90° with respect to the base of the specimen (Fig. 2a). The specimens were cured in water and air for 28 and 7 days respectively. For preparing reinforced specimens, two plastic pipes of 10 mm diameter were placed at a proper place in the mould before casting. The pipes were removed after 24 h of casting. This way two holes were prepared, which were used for installation of bolts. Steel bars of 6 mm diameter were used as rock bolts. Two bolts were installed perpendicular to loading direction and were grouted without any pre-tensioning (Fig. 2b).

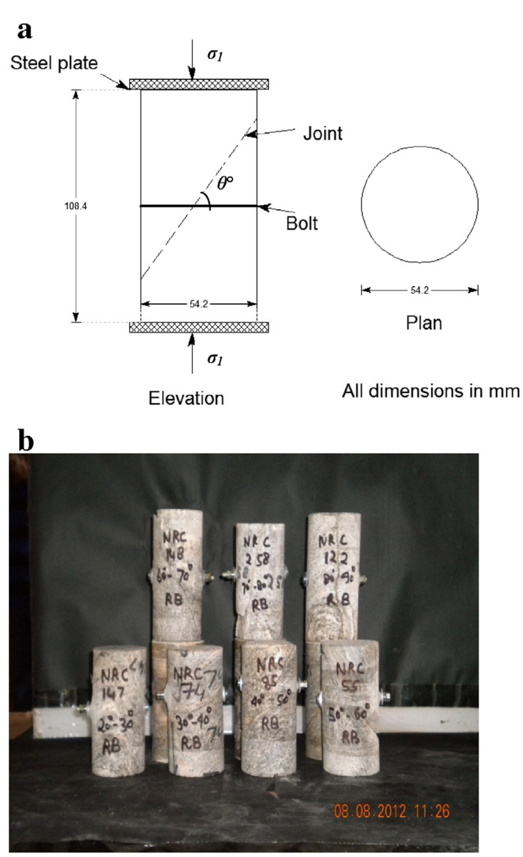

Fig. 1. a. Configuration of specimens of natural rock. b. Prepared reinforced specimens of natural rock.

Table 1
Constituents of synthetic rock (concrete).

Material	Ratio (by weight)	
	T2	T3
Cement	1	1
Coarse sand	1.27	0.75
Coarse aggregate	2.33	1.74
Silica fume	0.1	0.1
Water	0.36	0.25
Superplastisizer (Glenium 51)	0.175	0.30

3. Results and discussion

3.1. Material properties

Intact natural rock cores were tested for obtaining material properties and characterizing the material. Similarly, cores were drilled from concrete blocks and were subjected to routine tests i.e. physical properties, UCS and triaxial tests. In the case of natural rocks, the triaxial tests were conducted at confining pressure of 0, 5, 20, 40 MPa, respectively; while in the case of synthetic rocks, the tests were conducted at 0, 5, 10 and 20 MPa of confining pressure. The physical and engineering properties of the natural and the synthetic rocks are listed in Table 2. The tangent modulus (E_{t50}) was obtained from UCS test results by drawing a tangent to stress vs strain curve at a stress level equal to 50% of the

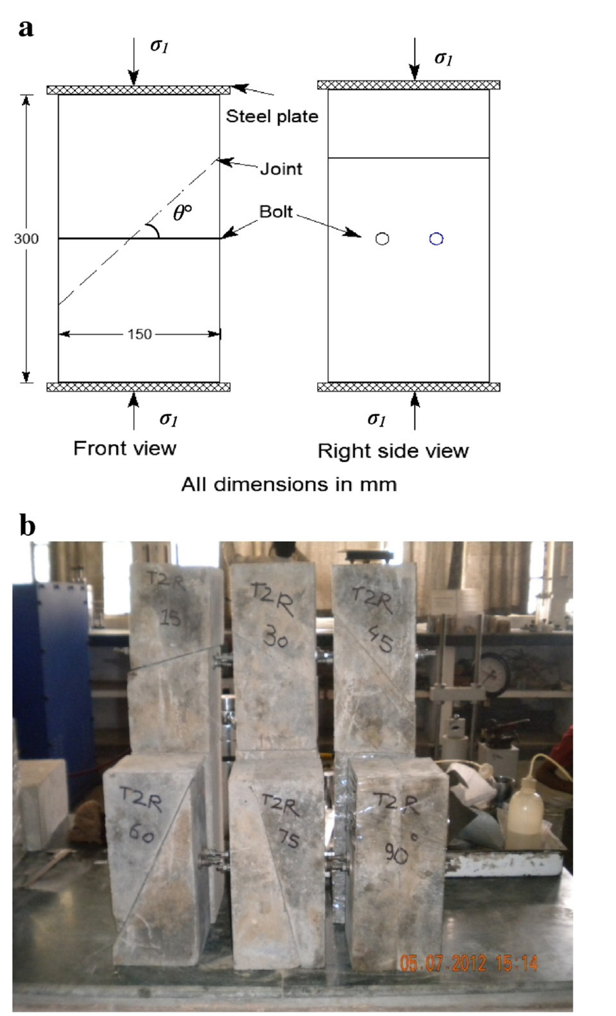

Fig. 2. a. Joint and bolt configuration in concrete specimens. b. Prepared reinforced specimens of concrete.