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Inflatable rock bolt bond strength versus rock mass rating (RMR): A comparative analysis of pull-out testing data from underground mines in Nevada

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ABSTRACT

The purpose of this paper is to establish confidence in anticipated minimum bond strength for inflatable rock bolts by comparing the bond strength to variable geotechnical conditions using the rock mass rating (RMR) system. To investigate a correlation between these parameters, the minimum bond strength of pull-out tested inflatable rock bolts was compared to the RMR of the rock in which these bolts were placed. Bond strength vs. RMR plots indicate that expected minimum bond strength is positively correlated with RMR; however, the correlation is not strong. Cumulative percent graphs indicate that 97% of pull-out tests result in a minimum bond strength of 3.3 and 1.7 ton/m in RMR $\geqslant$ 45 and <45, respectively. Although lower bond strengths are more commonly encountered in low RMR ground, high bond strengths are possible as well, yielding higher variability in bond strengths in low RMR ground. Bond strength of friction bolts relies on contact between the rock bolt and drill hole. Experience in Nevada indicates that RMR is known to affect both the quality and consistency of drill holes which likely affects bond strength. Drilling and bolting in low RMR ground is more sensitive to drilling and bolting practices, and strategies for maximizing bond strength in these conditions are discussed.

1. Introduction

Underground mines in Nevada are often characterized by highly-fractured, low-strength rock masses [1,2]. Most underground mines in Nevada use Swellex-type inflatable rock bolts due to their simple and fast installation procedure. These rock bolts are used in combination with wire mesh and shotcrete for most primary ground support. However, due to the highly-variable ground quality that can be found in these mines, performance of these rock bolts varies greatly. While rock bolts are a commonly utilized form of ground support, it is widely unknown what factors affect the bond strength that these bolts utilize. Rock bolts have been tested in locations that contain nearly identical rock qualities and produce highly varying bond strengths. Because of this high amount of variability, design bond strengths for these inflatable rock bolts is based largely off of the experience of geotechnical and mining engineers at each site. The primary means for determining design bond strength of rock bolts is through the use of pull-out tests.

1.1. Pull-out testing

Pull-out tests are performed on individual bolts by placing a set of "teeth" on a bolt head. These "teeth" are tightened around the bolt head, and then a hydraulic pump is used to pull on the bolt head. A typical setup for this type of equipment can be found in Fig. 1. This gear was originally developed by NIOSH and Thiessen Team, USA. Further information about the design of these bolt testers is highlighted by Martin et al. [3]. Underground gold mines in Nevada perform rock bolt pull-out tests to assess the strength of the rock bolts and bond strength, primarily for quality assurance/quality control.

2. Background

The data used in this study were collected from several underground gold mines from Northern Nevada referred to as Mine A, Mine B, Mine D, and Mine E. The data acquired from the mines include 1196 pull-out tests from Mine A, 191 pull-out tests from Mine B, 567 pull-out tests from Mine D and 222 pull-out tests from Mine E. The data collected from each of these mines are summarized in Table 1. Of the 2185 tests, only 470 of the tests had an

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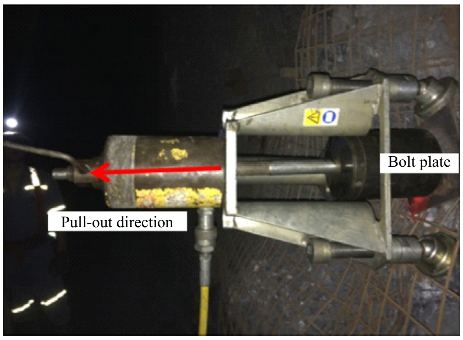

Fig. 1. Typical setup of an inflatable rock bolt pull-test gear.

Table 1
Data acquired from each mine.

Location	Total test	Total no slip	Total slip	Total destructive
Mine A	1196	988	199	9
Percent of total	55	55	57	17
Mine B	200	157	35	8
Percent of total	9	9	10	16
Mine D	567	436	109	22
Percent of total	26	25	3	42
Mine E	222	202	7	13
Percent of total	10	11	2	25
Total tests	2185	1783	350	52

associated RMR value from the area in which the bolt was tested. For pull-out tests that have an associated RMR, the RMR was obtained through geotechnical mapping of the drift or from the geotechnical model of the mine. In some instances, the rock tunneling quality index, Q was logged at the face and was later converted to RMR using Eq. (1) [4,5].

$$RMR = 9\ln(Q) + 44 \quad (1)$$

The geotechnical models of the mines were based on survey data and drill core taken and recorded by the mine personnel. Some of the data from the slip and destructive tests were eliminated from the data analysis due to various outside factors affecting the performance of the bolt, including under inflation, improper installation, and corrosion of the bolts being tested.

Previous research on the relationship between friction bolt pull-test results has been conducted by various researchers. In 2005, Brady discovered a strong correlation between bolt pull-out test values measured in tons per meter and RMR, with a distinction in bond strength occurring at an RMR value of 45 [6].

Soni also explored the relationship between RMR and pull-out test results. The focus of the study was on inflatable friction bolts [7]. Only slipped tests were analyzed in this study, yielding only 15 total tests. The limited results indicated that a possible correlation between RMR and bond strength could be established with further research on the topic.

Recently, Gregory published a study looking into a correlation between rock bolt pull-out strength and RMR [8]. This study was primarily focused on pull-out test results in rock with low RMR scores from underground mines in Nevada. This study, while it did contain a large number of data points, looked primarily into the correlation between slipped pull-out tests and RMR.

In an attempt to add data to the database developed by Gregory, as well as develop additional correlations, additional graphs have been generated taking into account tests in which the bolt did not slip, tests that did slip, and destructive tests that caused the bolt or the bolt head to yield (referred to as no-slip, slip, and destructive respectively, throughout the remainder of this paper).

The no-slip and destructive tests were included within the analysis due to the representation of a minimum bond strength achieved by the bolt being tested. Some of the no-slip tests also produced very low bond strength values. These instances occurred when the bolt test could not be completed in accordance with the proper testing procedure due to ground conditions, tester malfunction, or other issues that may have arose in the field.

3. Pull-out test results

Because the rock mass rating (RMR) system is so commonly used throughout Nevada mines, it was determined that the bond strength of the bolts will be compared with the RMR of the rock in which they were placed. In order to develop potential design bond strength, minimum bond strength must first be established.

3.1. Pull tests vs. RMR

By comparing the bond strength with the RMR, it can be determined whether a correlation between RMR and the minimum bond strength exists. It can be inferred from Fig. 2 that, while there is a fair amount of scatter within the data, there does appear to be some increase in minimum bond strength with an increase in RMR. This can be noted specifically for any of the bolts pulled in rock yielding an RMR greater than 45. Above an RMR of 45, only 12% of tests yielded minimum bond strength of 3.3 ton/m or less. Below an RMR of 45, 25% of tests yielded minimum bond strength of 3.3 ton/m or less. This is important to note, due to the common use of 3.3 ton/m as design bond strength in underground Nevada gold mines. Another important inference from this graph is that, while more data may exist that did not slip; these bolts were not pulled to a yield strength, so the bond strength for these bolts represents a minimum bond strength. In addition, some tests were not pulled to their maximum bond strength due to issues with the testing location or equipment. In order to effectively investigate the possible correlation between bond strength and RMR above and below 45, only the slipped tests will be investigated due to their representation of a maximum bond strength undergone by each tested bolt.

3.2. Slipped tests vs. RMR

Upon initial inspection of Fig. 3, it can be seen that, above an RMR of 45, only 16% of slipped tests (four tests) occurred below a maximum bond strength of 3.3 ton/m, while below an RMR of 45, 49% of slipped tests (32 tests) occurred below a maximum bond strength of 3.3 ton/m. It can also be noted that the bond strength and RMR appear to have a fair amount of scatter. While there does appear to be a somewhat positive trend, no apparent linear correlation exists between the two.

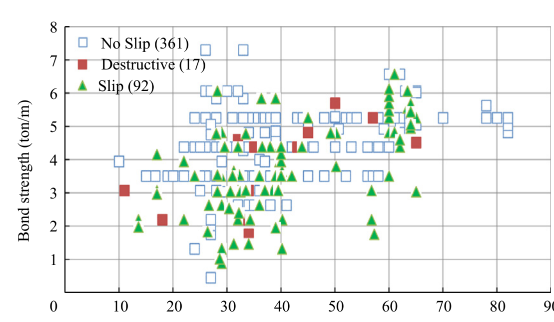

Fig. 2. Bond strength compared with the RMR taken from the ground in which the bolts were placed.