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Design and Testing of a Nondestructive Friction Bolt Tester

Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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By Lewis Martin, John Goris, and Lauren Roberts

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

kN	kilonewton	ft	foot
m	meter	lb	pound
mm	millimeter		

DESIGN AND TESTING OF A NONDESTRUCTIVE FRICTION BOLT TESTER

By Lewis Martin,[1] John Goris,[2] and Lauren Roberts[3]

ABSTRACT

The Spokane Research Laboratory (SRL) of the National Institute for Occupational Safety and Health (NIOSH) and Thiessen Team USA, Spokane, WA, have developed a pull claw that can be attached to any accessible friction bolt ring to test the performance (i.e., load-carrying capacity) of bolts without the use of a pull collar. This would allow true random testing of friction bolts, which need to be evaluated to determine if they are still providing an adequate level of support months or years after installation. Such support is critical to maintaining safe working conditions for underground miners.

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INTRODUCTION

The Spokane Research Laboratory (SRL) of the National Institute for Occupational Safety and Health (NIOSH) and Thiessen Team USA, Spokane, WA, have developed a bolt puller that can be attached to any accessible friction bolt ring to test the performance (i.e., load-carrying capacity) of bolts. Lauren Roberts of Barrick Goldstrike's Meikle Mine developed the first prototype of this device. The goal was to allow any friction bolt installed in the mine to be tested without the use of a pull collar. This would allow true random testing of friction bolts. The present practice of asking a miner to install a certain number of bolts with test collars does not result in an unbiased sample population because the miner could cluster the bolts in one easy-to-reach area. True random testing would lead to a better understanding of the field performance of friction bolts, and this information could be used to improve installation practices. In addition, bolts are often installed without test collars. Such bolts need to be evaluated to determine if they are still providing an adequate level of support months or years after installation. Ground water, acidic gases, and other conditions can corrode these bolts and reduce their effectiveness. This new tool will allow any friction bolt to be tested as dictated by field conditions.

Hard-rock mines in Nevada and Montana that use friction bolts as support systems are currently testing the capabilities of the pull claw. The test systems were obtained from Thiessen Team USA, which also provided technical assistance for use of the pull claw and interpretation of the pull tests.

DEVELOPMENT

In the first-generation pull claw, a device was inserted into the friction bolt past the ring and plate, and then a cone assembly was expanded. In stiff rock, the rock's confining force kept the device from pushing the wall of the friction bolt apart. However, the measurement reading of the initial pull-out load was false. In softer rock, the expander would tear the bolt apart in situ. Tests were conducted using the plate and ring as confinement, but not enough surface area was present for radial forces to overcome the pull-out strength of the bolts.

During tests of the second-generation pull claw, it was discovered that a ring welded onto a friction bolt would need a minimum contact area of 67% to begin a pull test without causing premature failure of the ring. Failure occurred when the ring was bent, ripped, or torn off the bolt. Slippage failures occurred when the pull claw did not have enough of a "bite" around the ring or the jaw half was not tightened adequately and the pull claw slipped off the ring.

Another problem was that the small amount of clearance left between the ring on the bolt and the backing plate after the friction bolt had been installed left only a small area of contact between the bolt and the rock surface, resulting in high shear loads on the lip of the jaws. Thus, to prevent shear failure, heat-treated, high-strength steel had to be used in the manufacture of the jaws.

The next piece of equipment was a two-piece pull claw that encompassed the welded ring on a friction bolt. This proved to be a sound concept, and the bolts could be pulled to ultimate failure in the same manner as pull collars. When this system was tested in the mine, however, investigators discovered that four bolts would be required instead of two if enough force were to be exerted on the shell to drive the claw around the welded ring.

The final production design is illustrated in figure 1. The device has three basic components: the jaws (No. 4), the carrier crow's foot, and the jack stand (No. 7). The jaws are available in standard 33-, 39-, and 42-mm sizes that allow pull tests to be conducted on different sizes of friction bolts using the same crow's foot. The screws on the crow's foot are designed to bring the two halves of the puller together and encompass the ring on the friction bolt, just as a standard pull collar works. The jack stand is made of aluminum to reduce the weight of the system. The pull screw is fitted with a fast-threading system for ease of installation.

INSTALLATION AND TEST PROCEDURE

If the back can be reached with a short ladder, the test equipment is light enough for a single person to carry. Special care should be taken when testing an overhead friction bolt, because the bolt might fail or the puller, jack, and stand could fall and injure test personnel.

Proper installation of the pull claw prior to testing is crucial. The bolt ring must first be inspected to determine whether it can be pulled or not. If the ring is accessible to about two-thirds of the circumference of the inner jaws, a test can be performed. Next, it must be determined whether the wall angle dips too steeply away from the ring. An adaptor set has a 15° capability to account for discrepancies in the wall and back rock.

The test assembly with the pull screw is first installed on the friction bolt ring. Prior to beginning the test, load must be parallel to the bolt. The four screws are just started in the jaw halves, then the pull claw is slipped over the ring with the carrier side at a slight angle to the axis of the bolt. The test assembly is then straightened so that the adjustable jaw side encompasses the ring (figure 2). An initial setting pressure of a few hundred kilonewtons of torque is applied to the bolts, and then the system is checked for alignment and contact of the hardened jaws on the ring of the bolt. With either a power drill or ratchet wrench, the bolts are tightened in a criss-cross pattern until the proper torque is reached.

With the test assembly securely fastened to the bolt, the angle rings and jack stand are put into place against the mine wall and kept from slipping with one hand. This is possible because the stand is light. Next, the hydraulic jack and speed nut are taken out and installed on the system with only a light hand torque on the nut. Now, the rings can be adjusted to keep the pull bolt in line with the friction bolt. With a slight twist of the nut, the test is ready to be commenced (figure 3).

During the test, displacement is measured to 1 mm in 4.4-kN increments. Loading continues until a displacement occurs without an increase in load or the yield point is reached, whichever occurs first. Load is released and the equipment is removed.

After the test is completed, a wedge should be placed behind the plate of the tested bolt to assure that the bolt remains useful as an active ground control member.

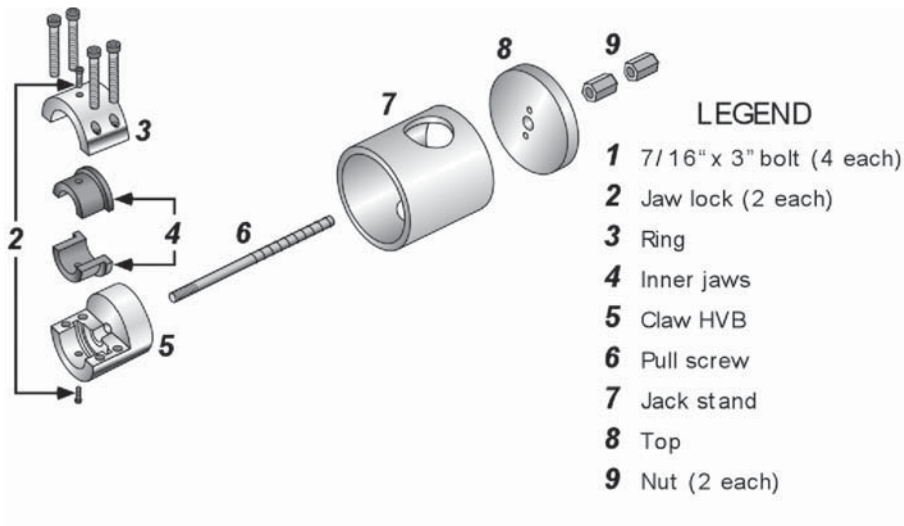

Figure 1.–Diagram of friction bolt puller assembly.

Figure 2.–Installation of pull claw on friction bolt.

Figure 3.–Complete test assembly installed on friction bolt.

Table 1. –Maximum loads during pull tests with pull claw and pull collars

Brand of bolt	Pull claw		Pull collars	
	Kilonewtons	Pounds	Kilonewtons	Pounds
B	64.5	14,500	62.3	14,000
B	64.5	14,500	68.4	15,500
A	66.7	15,000	69.0	15,500
A	71.2	16,000	71.2	16,000
A	71.2	16,000	75.6	17,000
B	80.1	18,000	82.3	18,500
A	86.8	19,500	84.5	19,000
B	102.35	23,000	102.35	23,000

Table 2.—Results of pull tests of friction stabilizers

Tonnes/meter	Pounds/foot	RMR	Tonnes/meter	Pounds/foot	RMR
Mine 2, 7/21/1999, 5-ft-long-bolt			3.4	2,400	80
3.1	1,958	70	4.0	1,536	80
3.5	2,162	70	2.6	1,440	80
3.2	2,026	70	2.4	960	80
3.2	2,026	70	2.2	1,344	80
3.2	2,026	70	3.3	1,968	80
3.2	2,026	70	1.8	1,056	80
Mine 2, 7/21/1999, 5-ft-long-bolt			2.4	1,440	80
1.0	625	50	1.8	1,104	80
1.4	875	60	1.8	1,056	80
1.3	813	50	2.0	1,200	80
1.1	688	50	1.2	720	80
2.0	1,250	60	2.6	1,584	80
1.1	688	50	2.9	1,728	80
Mine 3, 8/5/99, 5-ft-long-bolt			4.0	2,400	75
2.9	1,800	85	3.6	2,160	75
4.5	2,800	85	4.0	2,400	75
7.7	4,800	85	2.0	1,200	75
6.7	4,100	85	0.8	480	75
5.3	3,300	85	2.3	1,392	75
Mine 4, 1/19/2000, 5-ft-long-bolt			2.7	1,632	75
2.8	1,720	80	Mine 5, 2/9/2000, 6-ft-long-bolt		
3.1	1,920	80	2.3	1,467	65
3.4	2,120	80	2.7	1,700	65
3.6	2,240	80	2.6	1,600	65
3.5	2,180	80	1.9	1,200	65
Mine 4, 9/06/2000, 5-ft-long bolt			Mine 6, 6/21/2000, 6-ft-long bolt		
1.6	960	60	2.5	1,583	60
2.4	1,440	60	2.0	1,250	60
3.8	2,400	60	2.9	1,783	60
3.8	2,400	60	2.9	1,783	60
2.6	1,536	60	2.9	1,783	60
4.0	2,400	60	2.6	1,595	60
1.6	960	60	2.9	1,783	60
4.0	2,400	60	2.9	1,783	60
0.9	520	60	2.9	1,783	60
3.5	2,112	85	2.9	1,783	60
4.0	2,400	85	Mine 7, 6/04/2002, 6-ft-long bolt		
3.2	1,920	85	2.7	1,700	55
3.3	1,968	85	1.9	1,166	40
2.7	1,632	85	2.7	1,666	55
2.4	1,440	85	2.4	1,500	55
3.0	1,824	85	2.4	1,500	55
3.2	1,920	80	0.8	500	30
4.2	2,496	80	2.9	1,800	55
3.7	2,208	80	1.9	1,166	55
3.8	2,304	80	2.4	1,500	55
4.2	2,496	80	2.4	1,500	55
3.9	2,016	80			

FIELD TESTS

Extensive tests of the 39-mm friction bolts were carried out at six different underground mines in three different states. All the tests were conducted with the cooperation of mine personnel. The primary objectives of these tests were to (1) determine the reliability of the pull claw compared to conventional methods of testing using pull collars and (2) establish a reliable procedure for installing the pull claw assembly properly on bolts.

Table 1 shows results from pull tests conducted with both the pull claw assembly and pull collars on two different brands of 6-ft-long friction stabilizer bolts. Each bolt was installed with a pull collar and then tested with both the claw and the collars.

For each test, load was applied to the bolt until slippage occurred and the load dropped off, after which the bolt was re-tested using either the pull claw or the pull collars. Based on prior tests conducted on friction bolts, the industry standard of an average load of 1 tonne per meter of length in a 35-mm in diameter hole was recommended as a starting point for a mine pull-test program (Tomory et al. 1998; Min. Cong. J. 1959; ASTM 1999). As shown in table 2, each mine will have its own average pull-out strength, which will be higher or lower than the standard. The bolts are working properly in a given mine if the bolts are providing frictional resistance. The pull collar was also the industry standard.

The results show that the bolts exhibited approximately the same pull-out resistance regardless of the pulling mechanism used, that is, the collar-tested bolts and the pull-claw-tested bolts produced similar results. To produce similar results randomly on any bolt is of great benefit to mine personnel and increases safety, installation quality, and the accuracy of ground support analyses.

Additional tests using only the pull claw assembly were then conducted at the six mines. Table 2 shows the results of the tests. These data are representative of pull-out loads from multiple headings in underground mines. These pull-out loads were also correlated to the rock mass rating (RMR) (Bieniawski 1976) at the test location.

The field tests also led to a number of improvements, such as redesigning and heat-treating the inner jaws. In addition, the tests helped establish a reliable procedure for properly installing the puller on bolts and showed the limitations of the collarless test system. On average, mine personnel were able to conduct tests on about 40% of the bolts in any given area. The deciding factor was the condition of the ring on the friction bolt. If the bolt was installed at an acute angle to the bearing plate, then the ring is usually forced hard against the plate and at least one of the inner jaws of the pull claw will not be able to slip behind the ring. This condition is very common, especially for bolts placed in the ribs of an entry. Friction bolts placed in the back are less of a problem because the bolts are usually installed perpendicular to the bearing plate.

CORRELATING ROCK MASS RATING TO PULL-OUT LOAD

While testing friction bolts for pull-out loads, a rating of RMR 76 was calculated in the areas where the tests took place. Correlating RMR to pull-out load was important in determining if there were a trend in loads associated with different RMR values. Mines in Nevada use over 400,000 Split-Set[4] friction bolts as primary support. The data were analyzed for statistical relevance with an R-square test, but the data were too scattered. The data were then analyzed using a neural network (Ward System 2003) to normalize an expected curve that the data should fit. The neural net was superimposed over the data to determine trend and load support predictions (figure 4). The use of this neural curve data set will enhance a mine engineer's ability to determine the load expected from frictional ground support in a rated rock mass (table 3).

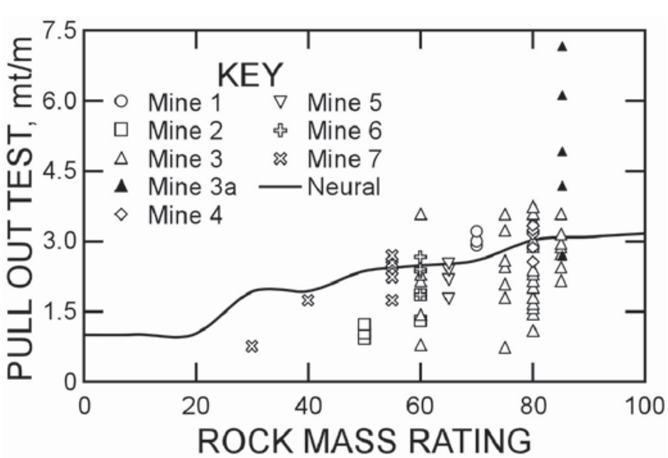

Figure 4.–RMR versus pull-out strength. A neural trend line is superimposed.

Table 3.–Predicted values for neural network

RMR	Tonnes/meter	Pounds/foot
0	1.06	666
10	1.07	672
20	1.10	693
30	2.07	1,295
40	2.08	1,303
50	2.53	1,583
60	2.66	1,663
70	2.78	1,740
80	3.25	2,034
90	3.30	2,080
100	3.40	2,124

[4]Mention of specific products or manufacturers does not imply endorsement by the National Institute for Occupational Safety and Health.

CONCLUSIONS

The friction bolt pull claw met the original design criteria of a mine engineer, that is, that the pull claw can be used to perform random tests on friction bolts to evaluate their performance. If the proper installation techniques are followed, a miner can evaluate the condition of bolts in areas suspected of being unstable. Unlike visual inspections that do not give a load profile of the ground support, the pull claw can indicate places where support is weak. A ground control engineer can also use the friction bolt pull claw to analyze the effectiveness of different bolt types, lengths, and hole sizes in a specific rock type in a given mine.

Weak ground conditions at several locations in six mines were documented with RMR values to determine a correlation between pull-out strength and RMR. The collection of these data will aid support engineers in determining support performance in specific rock types in their mines.

The friction-bolt pull claw will be able to produce results similar to those obtained using a pull collar test on any accessible bolt, which will be of great benefit to mine personnel and will enhance safety, installation quality, and ground support analyses.

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