Study of the Effect of Ratio of Hole Diameter to Rock Bolt Diameter on Pullout Capacity of Fully Grouted Rock Bolts

A. H. Ghazvinian*
M. Rashidi**

*Mining Engineering Department, Faculty of Engineering
Tarbiat Modares University
Tehran, Iran
Email: abdolhadi@yahoo.com*

**Mining Engineering Department
Islamic Azad University-Branch of Kerman
Kerman, Iran*

ABSTRACT

Fully grouted rock bolts are the most common reinforcements in geomechanical projects such as tunnels, rock slopes, and foundations. There are many factors, which directly affect the load-bearing capacity of rock bolts. However, there is only limited information about the effect of ratio of hole diameter to rock bolt diameter (D_h/D_b) on the pullout capacity. To evaluate this effect, 56 laboratory pullout tests have been carried out by using 25, 28 and 32 mm diameter (AIII) rock bolts in the holes with different diameters (32, 40, 50, 63, and 90 mm) and 180 mm embedment length. The results show significant changes between load bearing capacity of rock bolt and the ratio (D_h/D_b). The increase of diameter of the hole beyond an optimal limit leads to decrease of the load-bearing capacity.

Keywords: Rock bolt; Grout thickness; Pull out strength; Bond capacity; Rock bolt failure mechanism

1. INTRODUCTION

During the last four decades, the use of grouted rock bolts continues to become more common in civil and mining engineering. A grouted rock bolt is defined as a structural support comprising a tendon which is inserted into a drilled hole and grouted (ISRM, 1985).

In order to improve bolting design, it is necessary to have a good understanding of the behavior of rock bolts in deformed rock masses. This can be acquired through field monitoring, laboratory tests, numerical modeling and analytical studies. The support effect of rock bolt has been discussed by many researches (Hyett et al., 1992; Ito et al., 2001; Reichert et al., 1991; Stillborg, 1984 and Kaiser et al., 1992). However, the support effect of grout thickness has not been clearly studied yet. The aim of this research is to investigate the effect of ratio of hole diameter to rock bolt diameter on pull out capacity.

The basic factor in understanding of reinforcement system and its effect on excavation stability is to understand the concept of “load transfer” (Windsor, 1997). The load is transferred from the bolt to the host ground generally in shear, by a combination of chemical adhesion, mechanical interlocking and frictional resistance of the bolt-grout interface. The nature of load transfer depends primarily on the bolt type and the characteristics of cement grout.

The friction between grout and rock is usually more than that between rock bolt and grout. Therefore, sliding takes place at an interface which has the lowest strength (rock bolt-grout interface) after installation of rock bolt and beginning of rock movement (Aydan, 1989). So, the adhesive strength between rock bolt and grout is the actual controller of the magnitude of load in rock bolt.

Therefore, every factor which, in one way or another, increases friction angle of this surface or exert vertical force on it, has contributed to increase rock bolt capacity. With due attention to this, we can point to the properties of cement grout (additives, water-cement ratio, uniaxial compressive strength, shear strength, young’s modulus, curing time), properties of reinforcement element (diameter, embedment length, shape and surface conditions of rock bolt) and surrounding properties (rock properties, hole properties, lateral force exertion on the rock) as some of main factors affecting the capacity of fully grouted rock bolts (Rashidi, 2004). This laboratory testing program was executed to evaluate the effect of grout thickness on the load-bearing capacity of a threaded bar. To study this parameter, 56 pull out tests were conducted using AIII rock bolts.

2. EXPERIMENTAL PROGRAM

The PVC pipes with 32, 40, 50, 63, and 90mm outer diameters were installed in a network and concrete were scattered around them to prepare necessary hole diameters,. Before installation, outer layer of pipes were lubricated to the extent that they could easily be taken out of the concrete.

The pipes were taken out of concrete after 8 hours and thus some holes with desired diameters were created. During that period, pipes were rolled in the hole at the interval of every hour with the view that pipes do not stick to the concrete and can easily be taken out.

The holes were filled with water approximately 36 to 48 hours prior to installation. The water was then removed prior the installation of the anchor. This process reduces the loss of water from the grout to the surrounding concrete and ensures that there is no decrease in grout strength due to the excessive water loss.

AIII rock bolts with 25, 28, 32mm diameter and 180mm length were used in these experiments. To connect the rock bolts to coupling of pull out test set, all of them were looped to 6cm length (Fig. 1). The looped (threaded) parts with 22, 25, 28mm diameters were for rock bolts with 25, 28, and 32 mm diameters, respectively. These rock bolts have a tensile strength of 600 MPa and a young's modulus of 200 GPa.

The water-cement ratio (w/c) in grouting materials considerably affects pull-out strength of bolt. Although low w/c ratio gives the best bond strength, pumpability decreases and a number of difficulties in application are faced. In high w/c ratio, the pumpability of grouting materials into the holes is easy but the bond strength of bolt decreases. It is recommended by Reichert et al. (1991) that for the optimum compromise between grout pumpability and grout strength, w/c ratios in the range 0.35 to 0.40 is used. In this research, the rock bolts were grouted with simple Portland cement mortar that was made with 0.40 w/c ratio.

Since, the uniaxial compressive strength of grout has an important role on the behavior of rock bolts; the grout used in the holes was simultaneously sampled to determine uniaxial compressive strength. The samples were poured into 50mm cubic moulds and after 28 days, grout strength was measured simultaneously with the pull out test. Based on average results, the grout had a uniaxial compressive strength of 30 MPa.

Fig. 1 - Profile of the rock bolt used in the test program

Fig. 2 - Pull out test components

To study optimal ratio of hole diameter to rock bolt diameter, 56 pull out tests were carried out. The pull out test set-up is illustrated in Fig. 2. For 25 mm diameter rock bolts; 32, 40, 50, 63, and 90 mm diameter holes and for 28 and 30 mm rock bolts; 40, 50, 63, and 90 mm holes were used. After filling prepared grout mortar into the holes, bolts were inserted into the center of them to undergo pull out test after 28 days.

3. RESULTS AND DISCUSSIONS

As indicated in Table 1, tests were repeated 3 to 5 times to obtain more precise results. The average of these results is presented. Figure 3 shows an example of such averaging. The results of the pull out tests on 25, 28, and 32 mm rock bolts are shown in Figs. 4 to 6 respectively. The failure modes of rock bolts in these tests are summarized in Table 2.

Table 1- Number of pull out tests for each diameter of rock bolt and hole

D_b (mm)	D_h (mm)				
	32	40	50	63	90
25	5	5	5	5	3
28	N/A	4	5	4	3
32	N/A	4	5	5	3

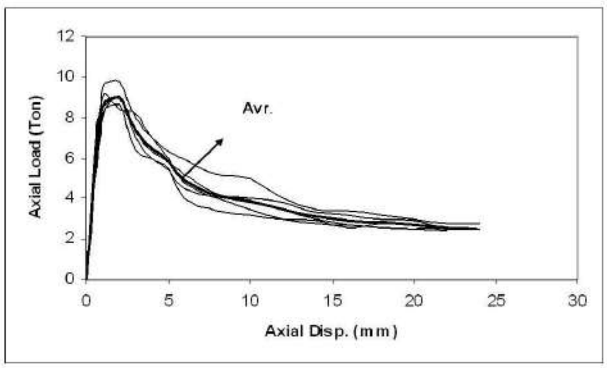

Fig. 3 - Averaging five test results for a 25 mm rock bolt in a 50 mm hole

Table 2- Failure modes produced in different rock bolt and hole diameters

D_b (mm)	D_h (mm)				
	32	40	50	63	90
25	G-H	B-G	B-G	B-G	B-G
28	N/A	G-H	B-G	B-G	B-G
32	N/A	G-H	B-G	B-G	B-G

B-G: Failure in rock bolt and grout interface.
G-H: Failure in hole and grout interface.
N/A: Not Available.

From the observed results the following points can be made:

- Due to good bonding between rock bolt and grout, once grout thickness is low, rock bolt comes out of the hole along with grout.
- Increasing in grout thickness increases contact surface of grout and concrete and therefore, the rock bolt comes out of the hole by breaking its surrounding grout.

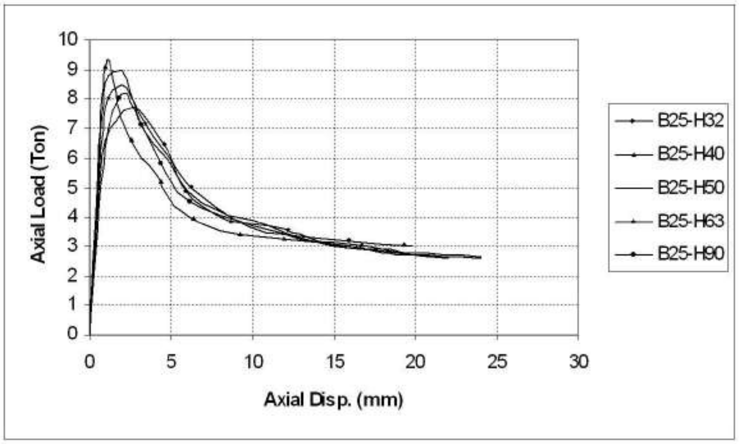

Fig. 4 - Results of pull out test for 25 mm rock bolt in the holes with different diameters

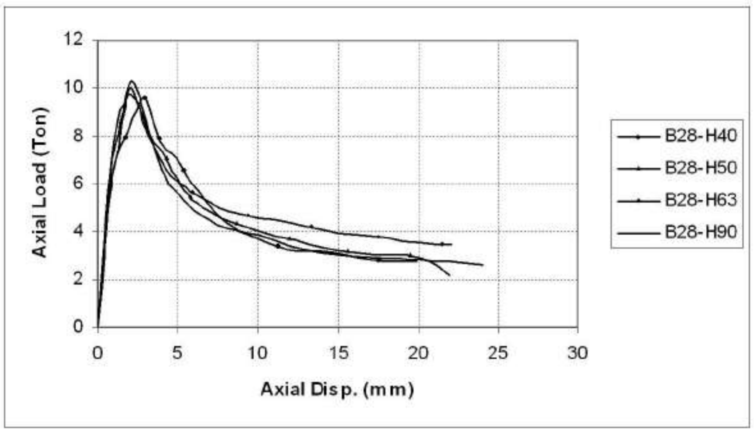

Fig. 5 - Results of pull out test for 28 mm rock bolt in the holes with different diameters

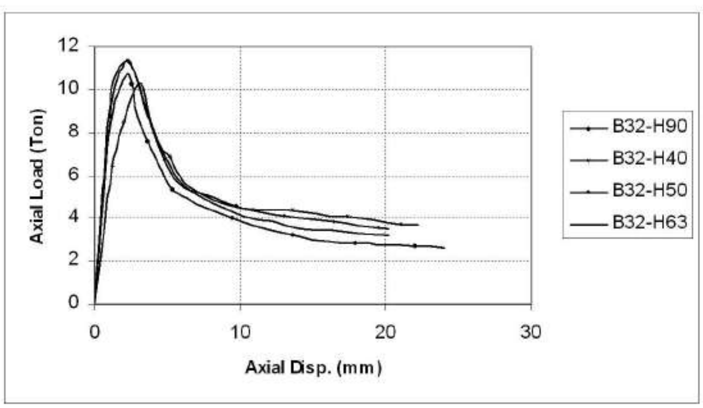

Fig. 6 - Results of pull out test for 32 mm rock bolt in the holes with different diameters

- When grout thickness is low, cracks expand to the grout surface due to pull out test. However, it does not happen, if thickness is increased.

Based on Figs. 4 to 6, the dependency between maximum pull out load and hole diameter to a rock bolt diameter is not linear. This trend is shown in Fig. 7 for different bolt diameters. It is found that when the rock bolt and the hole have 25 mm and 32 mm diameter, respectively, the pull out capacity of rock bolt is 7.72 tons. By increasing diameter of the hole to 40 mm, this capacity also increases to 9.1 tons. However, with the increase of hole to 48 mm diameter, the pull out capacity of the rock bolt does not change much and even the load is at the maximum level. So, the hole between 40 mm and 48 mm diameter is the best range for the 25 mm diameter rock bolt.

By increasing the diameter of the hole more than this range, maximum pull out load decreases considerably (5% to 15%), which also point to the significance of determined optimal range. This is due to the fact that the grout in the hole tends to expand and as such, brings some cracks along it. For large hole diameters, a higher degree of separation must occur. Alternatively, the ability of anchorage system to resist separation reduces with large grout annulus. Hence the anchorage system with an unduly large grout annulus is less likely to perform as an effective rock support mechanism.

Similarly, for the 28 mm and 32 mm diameter rock bolts 47 mm to 55 mm and 54 mm to 62 mm diameter holes, respectively are the best range. These findings are drawn upon estimated optimal ratio of the hole to the rock bolt diameters in Fig. 8.

Use of logarithmic relation is not very suitable although it is the best graph that fits the data. By using linear relation, the best possible situation is when diameter of the hole is about 1.7 to 1.9 times of rock bolt.

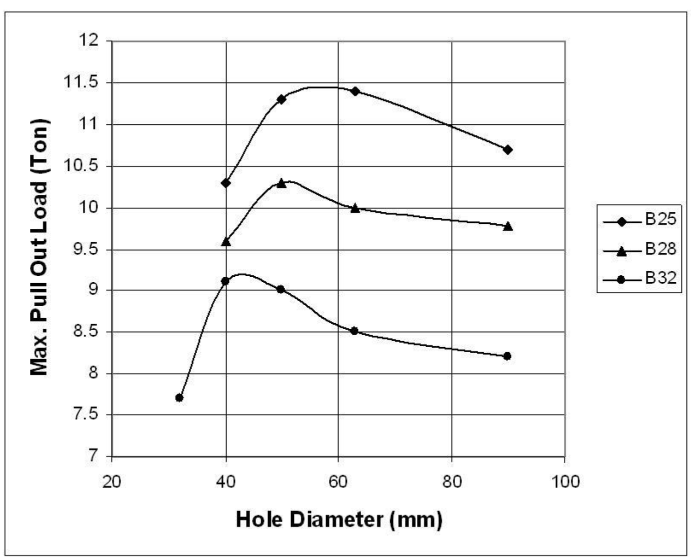

Fig. 7 - The relation between maximum pull out load and hole diameter for three different diameters of rock bolt

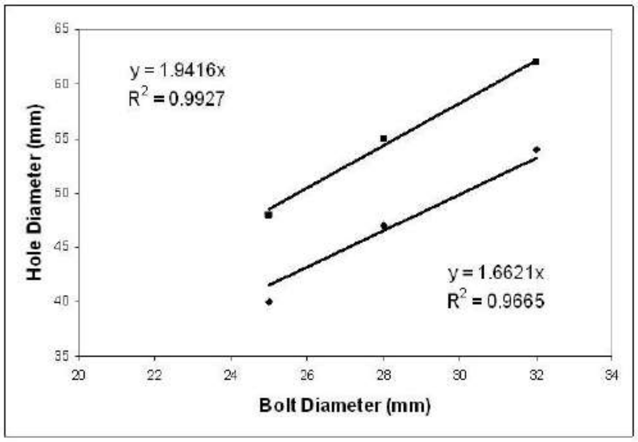

Fig. 8 - The optimal range between hole diameter and rock bolt diameter.

4. CONCLUSIONS

In this investigation, experimental results on the evaluation of grout thickness and pull out behavior of fully cement grouted rock bolts were reported. Laboratory tests on three common rock bolts in the holes with different diameters were conducted following the test procedures described. The following conclusions are offered.

- Due to good bonding between rock bolt and grout, when grout thickness is low, rock bolt comes out of the hole along with it. Increase in grout thickness increases contact surface of grout and concrete and consequently, contact between grout and hole is maintained and rock bolt comes out by breaking grout.
- When breakage occurs at the interface of grout and hole, the least values are obtained for pull out load, showing the significance of optimal thickness of grout.
- Based on experimental results, the best situation is that hole diameter should be 1.7 to 1.9 times to rock bolt diameter.
- If diameter of the hole is more than the optimum range, considerable reduction (5% to 15%) takes place in the maximum pull out load.

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