Tunnelling and Underground Space Technology 59 (2016) 16–23

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

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

Critical embedment length and bond strength of fully encapsulated rebar rockbolts

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ARTICLE INFO

Article history:
Received 9 November 2015
Received in revised form 7 June 2016
Accepted 8 June 2016

Keywords:
Rockbolt
Embedment length
Pullout test
Bond strength

ABSTRACT

A series of rock bolt pull tests were carried out in the laboratory to determine the critical embedment length of a specific type of fully cement-grouted rebar bolt. The rebar bolt is 20 mm in diameter, and it is widely used in underground excavations in Norway. Three water-cement (w/c) ratios were used in the tests. It was discovered that the critical embedment length of the rock bolts was approximately 25 cm for the water-cement ratio 0.40 (the corresponding uniaxial compressive strength (UCS) of the grout is 37 MPa), 32 cm for the ratio 0.46 (UCS 32 MPa), and 36 cm for the ratio 0.50 (UCS 28 MPa), for the specific type of cement, Rescon zinc rock bolt cement. It was found that the bond strength of the rock bolt is not a constant but is related to the embedment length. The bond strength was linearly proportional to the UCS of the grout.

1. Introduction

The rebar rock bolt that is fully encapsulated in a borehole with cement mortar or resin grout is the type of rock bolt widely used in civil and mining engineering. The wide use of this type of rock bolt is predominately owed to its high load-bearing capacity. The grouting quality and performance of the rock bolt are usually examined by pull test. In such a test, a rock bolt grouted in a borehole is either pulled out to measure the bond strength in the case of a short embedment length (Hyett et al., 1995; Benmokrane et al., 1992; Benmokrane et al., 1996; Zhao and Yang, 2011) or pulled until failure of the rock bolt shank (Stillborg, 1994; Stjern, 1995; Chen and Li, 2015). Pull tests may be conducted in the field (Franklin and Woodfield, 1971; Franklin et al., 1974; Bjurholt, 2007; Soni, 2000) or in laboratories (Ito et al., 2001; Li et al., 2014).

The performance of a fully grouted rebar rock bolt is very much affected by the bond at the rock bolt-grout interface. The bond strength directly determines the critical embedment length of the rock bolt, which refers to the longest encapsulated length at which the rock bolt is pulled out of the borehole. The rock bolt will fail in the shank if the grouted section is longer than the critical embedment length. For instance, in order to stabilise a loosened rock block with fully grouted rock bolts, the length of the rock bolt portion that is installed in the stable stratum must be longer than the critical embedment length. The quality of grouting and the load-bearing capacity of grouted rock bolts are often examined through pull tests in the field. One of the concerns with such a pull test is whether the performance of the rock bolt is negatively affected by the pull test. The authors acknowledge that the issue of the critical embedment length was studied by others in conjunction with individual engineering projects, but little information about it can be found in the literature. Therefore, a series of tests were carried out at the Laboratory of Rock Mechanics at the Norwegian University of Science and Technology to determine the critical embedment length of a specific type of 20 mm rebar rock bolt using the cement mortar Rescon zinc rock bolt cement mix in three different water-cement ratios. Both the rock bolt and the cement mix are widely used for rock support in Norwegian tunnels and underground caverns. The test results are reported in this article. In addition to the determination of the critical embedment length, the bond strength of the fully grouted rock bolts was also studied. It was found that the bond strength is not a constant but is related to the embedment length.

2. Specimens

2.1. Rock bolts

The type of rebar rock bolt tested is 20 mm in diameter, which is widely used in road tunnels in Norway (Fig. 1). It is made of steel B500NC according to the Norwegian standard NS 3576-3, which specifies the mechanical properties of the steel, the formation of the rib pattern, and the production control. For the sake of

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http://dx.doi.org/10.1016/j.tust.2016.06.007
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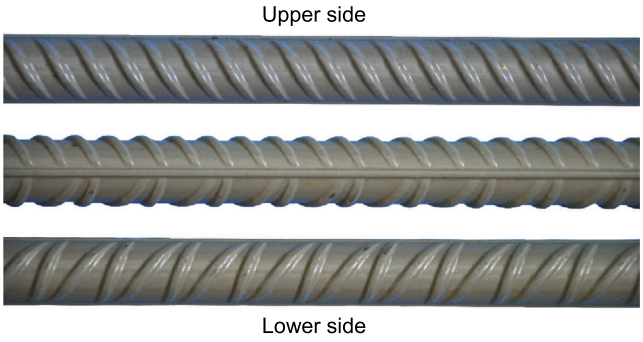

Fig. 1. The rib pattern of the rebar bolt, viewed in three orthogonal directions. Bolt diameter 20 mm, rib spacing approximately 12.5 mm.

corrosion protection, the rock bolt surface is treated by hot zinc-galvanisation with a minimum thickness of 65 μm and a coating of epoxy powder with a minimum thickness of 60 μm. The characteristic yield and ultimate tensile loads of the bolt are 157 kN and 188 kN, respectively.

2.2. Cement grout

The grouting agent used in the tests is Rescon zinc rock bolt cement mix, which is used for grouting rock bolts in road tunnels in Norway. The cement mix is made of cement (c) and silica (s). The weight ratio of the mix (cement and silica) to the cement is (c + s)/c = 1.7. The ratio of the mix (c + s) to the water (w) has the following relationship with the conventional water-cement ratio (w/c):

$$\frac{w}{c+s}=\frac{c}{c+s}\frac{w}{c}=\frac{1}{1.7}\frac{w}{c} \quad (1)$$

For instance, the ratio of w/(c + s) should be 0.235 if the water-cement ratio of the grout is intended to be 0.40. Three water-cement ratios, 0.40, 0.46, and 0.50, were used in the tests and the corresponding water-mix ratios (i.e., w/(c + s)) were 0.235, 0.270, and 0.294, respectively.

Table 1
Number of rock bolt specimens for every water-cement ratio and for every embedment length.

Embedment length (cm)	Water-cement ratio		
	0.40	0.46	0.50
10	3	3	3
15	3	–	–
20	3	3	3
25	–	3	–
30	3	3	3
40	1	–	2
Total	13	12	11

3. Testing

3.1. Test plan

The embedment length of the rock bolt was varied for every water-cement ratio in order to find the critical embedment length. In general, three rock bolt specimens were pulled for every embedment length. The number of rock bolt specimens for every embedment length and every water-cement ratio is given in Table 1.

The uniaxial compressive strength (UCS) of the grout was measured after the same curing time as the tested rock bolts. Three cubic grout specimens, 100 × 100 × 100 mm in size, were prepared when the rock bolt was grouted and then tested on a servo-controlled test machine, GCTS RTR-4000, on the same day the rock bolt was tested.

3.2. Test arrangement

Boreholes were percussively drilled with a 48 mm drill bit in a cubic concrete block with a dimension of 950 × 950 × 950 mm. The UCS of the concrete is approximately 110 MPa. The grout was mixed with one of the water-cement ratios given in Table 1. The ready-mixed grout was pumped into the hole and the rock bolt was inserted to a desired depth. The curing time was scheduled to be seven days, but some of the rock bolts were pulled out after eight days. When a rock bolt was tested, a cylindrical spacer, collaring the rock bolt, was placed on the top of the concrete block, a hydraulic cylinder (jack) was placed on the top of the spacer, and finally a rock bolt plate and a barrel-and-wedge unit were placed on the top of the setup string to fasten the rock bolt (Fig. 2). The purpose of using the barrel-and-wedge to replace the nut and thread is to avoid premature failure of the rock bolt in the thread. With such an arrangement, the rock bolt does not need to be threaded so that the rock bolt head is not weakened due to threading. Thus, the failure occurs either in the grout along

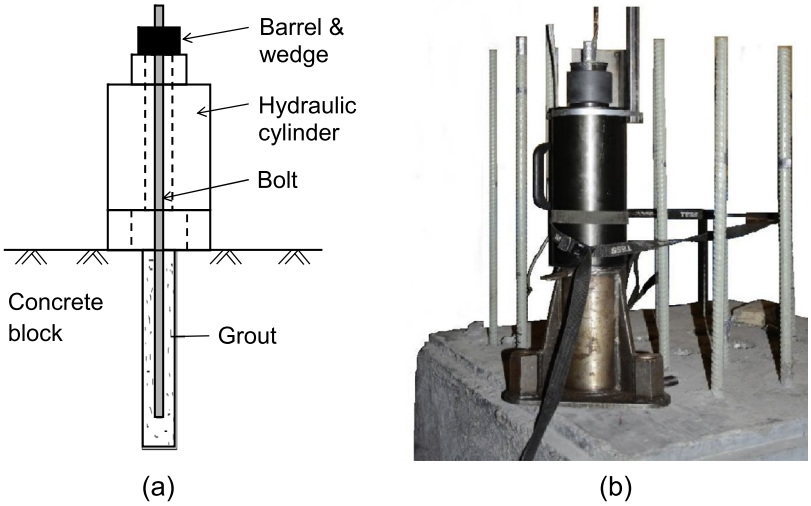

Fig. 2. Pull test arrangement. (a) A sketch and (b) the test arrangement.