# Length Effect on Load Bearing Capacities of Friction Rock Bolts

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**Abstract**

Change in the load bearing capacity of the split set type friction rock bolts with variations of bolt lengths was investigated within this study. To determine a relation between the load bearing capacity and bolt length parameters, different friction bolt models with various lengths were analyzed with a numerical modelling study. In addition, a series of pull-out tests was carried out to evaluate the load bearing capacities of the split set type friction rock bolts with different lengths. The load bearing capacity of the bolts was found to decreasingly increase with the increase in the bolt length. As an outcome of this study, a relation between the load bearing capacity and rock bolt length parameters is suggested in accordance with the results obtained from both numerical and experimental studies.

**Keywords**

friction rock bolts, split sets, pull-out test, load bearing capacity

## 1 Introduction

For a long time, rock bolts have been used for the purpose of reinforcing and supporting underground excavations in civil and mining engineering. According to their anchoring mechanism, rock bolts can be classified into various groups. The friction bolts are a type with the ability to supply support pressure due to the friction between the bolt shanks and the rock surfaces of drill holes. The split sets consisting of the tube and plate parts are the first and most widely used type of friction rock bolts. As split sets are inserted into drill holes with slightly lower diameter than that of the rock bolts, the radial spring force is generated by the compression of the tube with a slit in the cross-section of $C$ shape. The compression of the tube provides the frictional anchorage in drill holes.

The split sets are popular in rock engineering because of their advantages such as practical application, being able to directly start bearing load as being inserted, retaining a close load bearing capacity to its peak despite the high deformations in tunnels. Even though the sliding at the friction interface starts, spit sets can supply a good support pressure depending on various parameters such as the normal stress at the friction interface, the friction coefficient and friction bond length [1–3].

The split sets used in rock engineering generally have lengths from 2 meters to 3 meters. Depending on the site, split sets can also be applied with different lengths varying from one meter to four meters [4–7]. For supplying a sufficient support pressure, the friction bond length should be enough long. It is well-known that length is an important parameter for load bearing capacities of rock bolts. The load bearing capacity increases with an increase in rock bolt lengths. On the other hand, variations in the load bearing capacity per unit length is another topic to investigate whether the length effect on the load bearing capacity is diminished in case of using high bolt lengths. The relation between changes in the friction bolt length and the load bearing capacity was aimed to be investigated in detail by this numerical and experimental study.

A popular test to determine load bearing capacities of rock bolts, the pull-out test was performed in the experimental part of this study. The purpose of the pull out test is to evaluate the bearing capacities of rock bolts under axial loading condition. The pull-out test helps to verify the effectiveness of rock bolts. In the test, split sets inserted into drill holes were held from the collars at the back ends of the tubes and pulled out by the hydraulic jack of the

equipment. The axial load is applied on the rock bolts. In the pull-out tests of the friction rock bolts, the load capacity is the maximum load borne by the friction bond between rock and bolt surfaces, which is generally reached just before the start of sliding of the steel tube of split sets. The steel split sets can be moved sliding in drill holes under a slightly lower load than the peak values. As the split set tubes need nearly constant and a close load level to the peak load to keep their sliding in the drill holes, ideal support reactions are obtained from them [8–10]. That kind of load and displacement behavior makes the split set bolts to have good amount of energy absorption capacity [11–15].

The stress distribution in the bolt steel and maximum stresses induced in the bolt body vary with the change in the bolt length. In case of longer friction bond lengths than a critical length, bolt steel fails instead of the sliding at the friction surface. Therefore, the friction load bearing capacity also depends on the bolt material strength as well as the friction coefficient, stresses on the friction surface and the bolt length [16–18]. Even if the friction load capacity can be bettered by modifications in various parameters for increasing the friction performance, the bolt bearing capacity maximizes at a load causing the yield of the bolt shank.

## 2 Numerical study
### 2.1 Methodology
To investigate their frictional load bearing capacities, rock bolts with different lengths (1 m, 2 m, 3 m, 4 m, 5 m) were modelled. The split set tubes with the outside diameter of 30 mm were fully contacted into the drills in rock blocks with 350 mm × 350 mm width and height sizes and a meter higher length than those of the bolts. As shown in Fig. 1,

the pull-out test was modelled by axial loading in the direction of the bolt shanks. Load was applied from the bolt end being outside of the drill hole. The mesh size in the rock models was chosen to be 2 mm around drill holes where is the most critical part for the start of failure and increase from 2 mm by depending on the distance from the drill hole wall (Fig. 1). Various finite element models with different meshes were analyzed in an effort to ensure that the selected meshes are dense enough to provide sufficient solution convergence. In the steel rock bolt models, the mesh size was selected to be vary about 2 mm, which slightly increased from the inner to outer side of the $C$ shape tube cross-section. On the other hand, the mesh size along the bolt length was constant and 2.5 mm. Some figures of bolt-inserted rock block models with different lengths are given in Fig. 2.

Eight-node solid brick elements (Solid65) were used for the three-dimensional modelling, which have the capability of cracking in tension, crushing in compression, plastic deformation, and three degrees of freedom at each node, including transition in the nodal $x$, $y$ and $z$ directions. Rock and steel materials were modelled by considering the linear and non-linear properties defining the behaviors of the elements. The rock models were defined as linear elastic until the crack initiation occurs. After the crack initiation, change of the normal and shear stresses has been re-calculated by the program. The re-calculated shear stresses were transferred by the plasticity due to the generated open and closed cracks. The bolt steel material models were defined as linear elastic until the yielding stress is reached. The steel material was modelled to plastically deform under constant load level. However, quite high bolt lengths to reach the yield strength values of the steel material were not analyzed in this study due to the aim of investigating
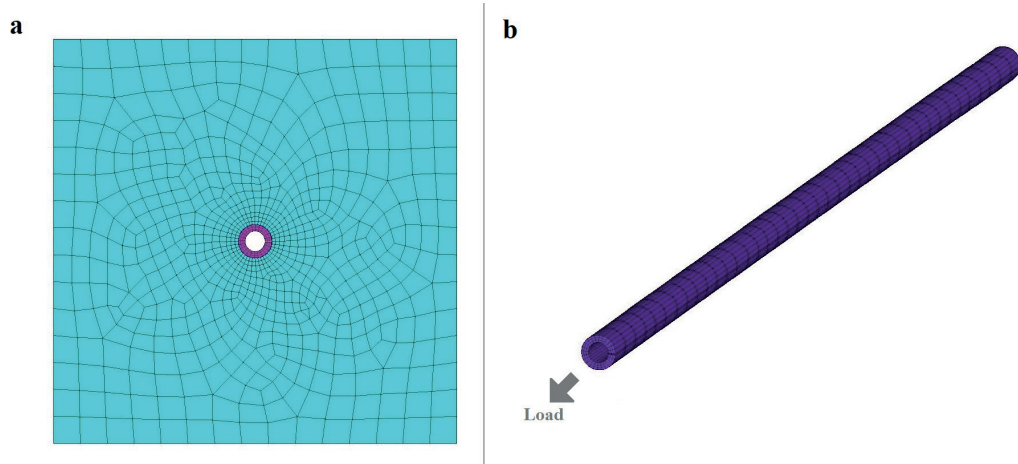


**Fig. 1** Numerical models and meshing: a) cross-section of a tube inserted rock block, b) a bolt model
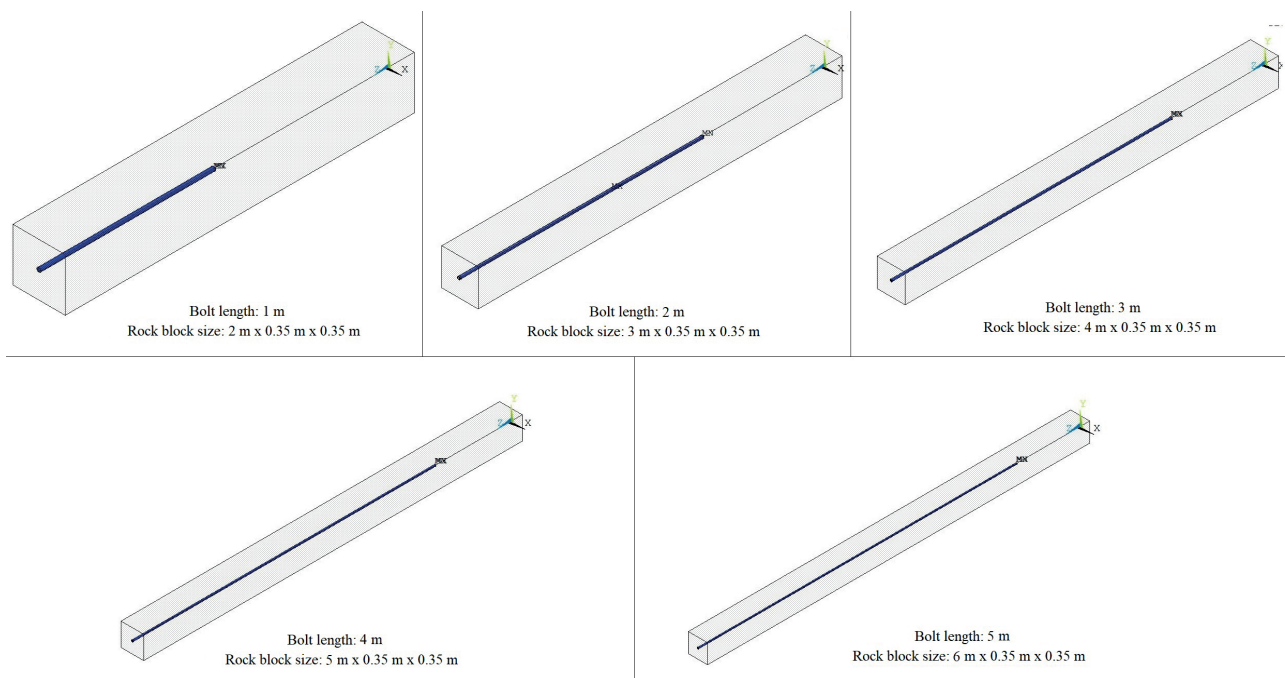
**Fig. 2** Rock bolt inserted rock blocks with different lengths from 2 m to 6 m (Rock bolt lengths from 1 m to 5m)

the friction capacity change. In the numerical models, the sliding started as the adhesion between bolt steel and rock surfaces is achieved and continued under a constant load level. The normal stress applied to the contact between rock and bolt steel was 0.5 MPa in the numerical analyses. For applying the normal stresses at the contact, hydrostatic pressure was applied from inside of the steel tube.

For the displacement-controlled loading, loads were divided into multiple sub-steps until the total load was achieved. Stress distributions and failure mechanisms were plotted for all the models. A static analysis was performed for each of the models, and the full Newton–Raphson method was used for non-linear analysis. The material properties for rock, bolt steel and friction interface of rock and bolt contact are given in Table 1. To neglect the failure of steel and failure in rock material, relatively high strength values were selected for rock and steel materials. The steel and rock failures were theoretically eliminated in this study to investigate the load bearing capacity of the friction surfaces for a wide change in the bolt length.

**Table 1** Material properties in the numerical study

| Property | Rock | Bolt | Friction interface |
|---|---|---|---|
| UTS (MPa) | 20 | 330 | 0 |
| UCS (MPa) | 200 | 350 | 200 |
| E (GPa) | 100 | 250 | - |
| $v$ | 0.27 | 0.25 | - |
| Adhesion (MPa) | - | - | 5 |

To investigate whether friction forces at the bolt and rock contact have an effect on relation between length and the load bearing capacity parameters, different friction coefficient values ($\mu$) of 0.2 and 0.5 were used in numerical analyses.

**2.2 Results**
According to the results of the numerical analyses, the tensile strain values increase from front end to the back end which is the load applying side of the bolts. As seen in Fig. 3, the maximum stress in the bolt shank is induced at the back end part. Because of the increase in strain of the steel, the friction forces at the contact of the rock and bolt steel surfaces also maximize at the back end part. Therefore, the critical location for the start of the adhesive failure was found to be the entrance part of drill holes where is near-by the load applied. As the stresses at the friction interface reached its maximum value, the bolt shank started to slide in the hole. The pull-out test loads and maximum stresses induced in the bolt shanks at the start of the sliding in the hole are given in Tables 2–4, respectively. Additionally, changes in the pull-out test loads per bolt length parameter are shown in Fig. 4 and Fig. 5. According to the results obtained from the numerical analyses, load bearing capacity and the bolt length parameters were related as seen in Eqs. (1) and (2), which respectively give the change in load bearing capacity per a unit bolt length and load bearing capacity of the total bolt

length. It should be noted herein that the suggestions given in the following equations are exclusively for split set type rock bolts with different lengths from 1 m to 5 m.

$$F_p = F_1(1 - 0.12(n-1)),$$ (1)

$$F_t = F_1\left(1 - 0.12(n-1)\right)n = F_1\left(n - 0.12n^2 + 0.12n\right),$$ (2)

where, $n$ is the bolt length (m), $F_1$ is load bearing capacity of bolts with 1 m length (kN), $F_p$ is load bearing capacity of bolts per 1 m length (kN/m) and $F_t$ is the maximum pull-out test load of a bolt with n meters length (kN).
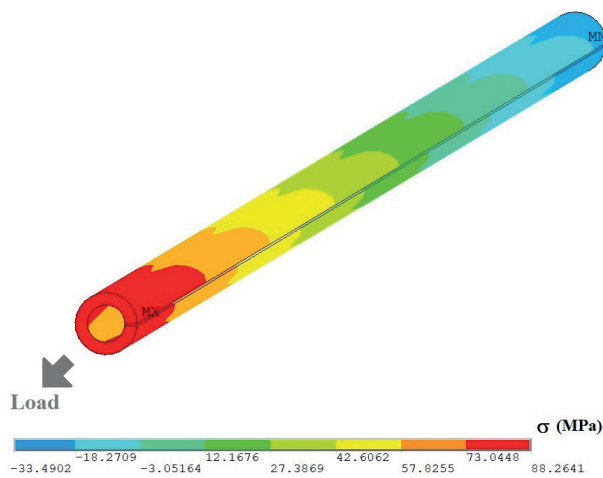


**Fig. 3** Stress distribution through the bolt body with 1 m length (not to scale, $\mu$: 0.5)

**Table 2** Load bearing capacities of rock bolts with different lengths ($\mu$: 0.5)

| Bolt length (m) | Load bearing Capacity (kN) | Load capacity per meter (kN/m) |
|---|---|---|
| 1 | 19.5 | 19.5 |
| 2 | 34.3 | 17.2 |
| 3 | 41.0 | 13.7 |
| 4 | 47.7 | 11.9 |
| 5 | 50.8 | 10.2 |

**Table 3** Load bearing capacities of rock bolts with different lengths ($\mu$: 0.2)

| Bolt length (m) | Load bearing Capacity (kN) | Load capacity per meter (kN/m) |
|---|---|---|
| 1 | 13.4 | 13.4 |
| 2 | 23.8 | 11.9 |
| 3 | 29.1 | 9.7 |
| 4 | 33.5 | 8.4 |
| 5 | 35.4 | 7.1 |

**Table 4** Maximum stresses in the bolt shank when the load bearing capacity is reached

| Bolt length (m) | Maximum tensile stress in the bolt shank (MPa) | |
|---|---|---|
| | $\mu$: 0.5 | $\mu$: 0.2 |
| 1 | 88 | 60 |
| 2 | 150 | 101 |
| 3 | 213 | 142 |
| 4 | 271 | 184 |
| 5 | 326 | 229 |



a)
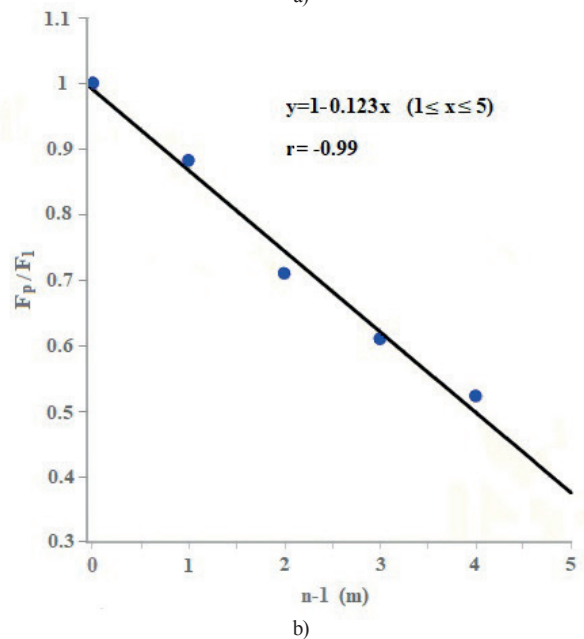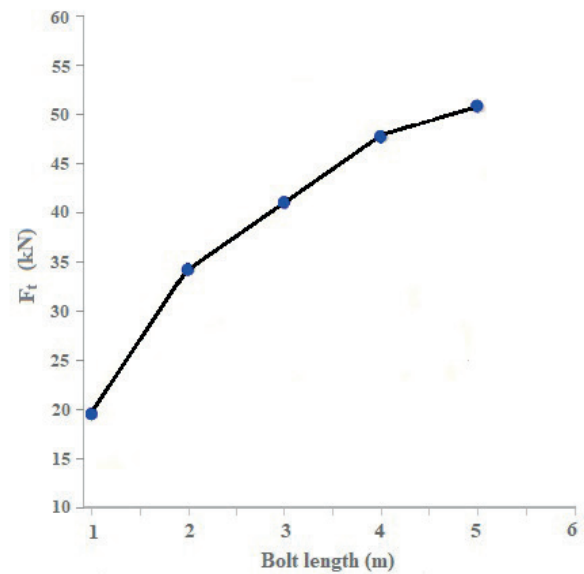


$y = 1 - 0.123x$ $(1 \leq x \leq 5)$

$r = -0.99$

b)

**Fig. 4** Load bearing capacities for different bolt lengths ($F_t$: load bearing capacity of a bolt, a) $F_1$: load bearing capacity of bolts with 1 m length, b) $F_p$: load bearing capacity per 1 meter length ($F_p = F_t/n$), $n$ is the bolt length, $\mu$: 0.5)
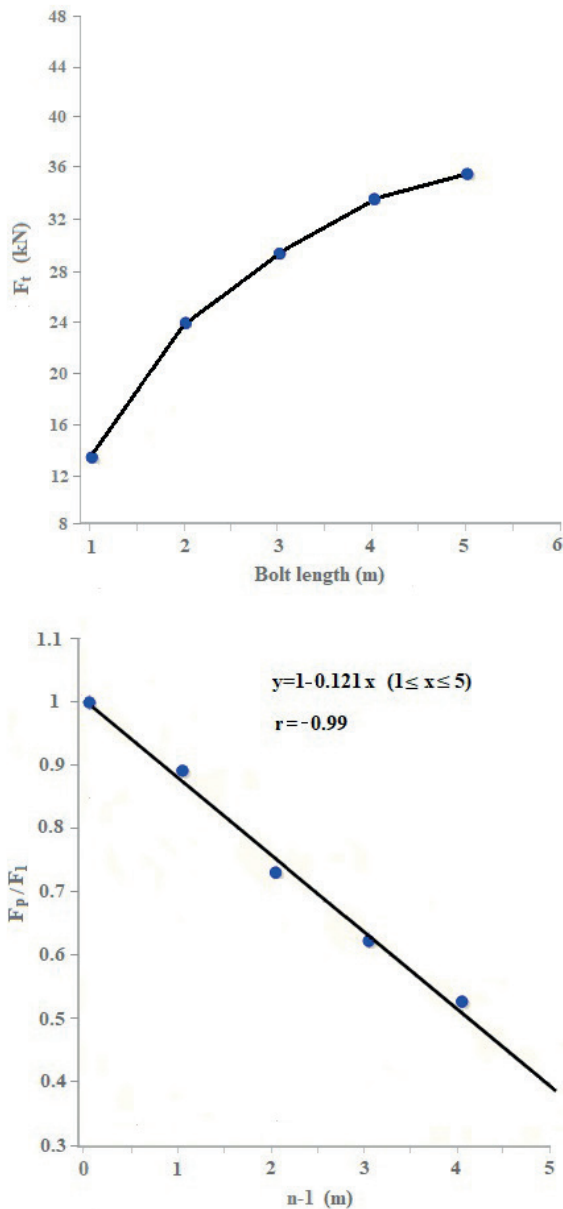
Fig. 5 Friction load capacities for different bolt lengths ($\mu$: 0.2)

## 3 Experimental study

### 3.1 Materials and methods

A field study was performed at the Akarsen copper mine, which is an underground rock engineering site in Artvin, a city in the Black Sea region of Turkey. The split set tubes with different lengths of 1.0 m and 2.5 m were purchased from the same manufacturer and used in the field study (Fig. 6). Both of the split sets are made of same steel material and have same nominal diameter of 39 mm. The steel split sets with the nominal diameter of 39 mm were installed in drill holes of 36 mm diameter, using a rock bolter machine which is able to first drill holes into the rock mass and insert bolts later on. In total, 18 rock bolts were inserted into the holes drilled in three different rock

formations of the mine. Within this field study, a chalcopyrite ore, limestone and dacite formations were chosen for investigation of the length effect on the load bearing capacities of the bolts inserted in various rock contact conditions. A day after the installation of the rock bolts, load bearing capacities were evaluated carrying out the pull-out test in the mine (Fig. 7).
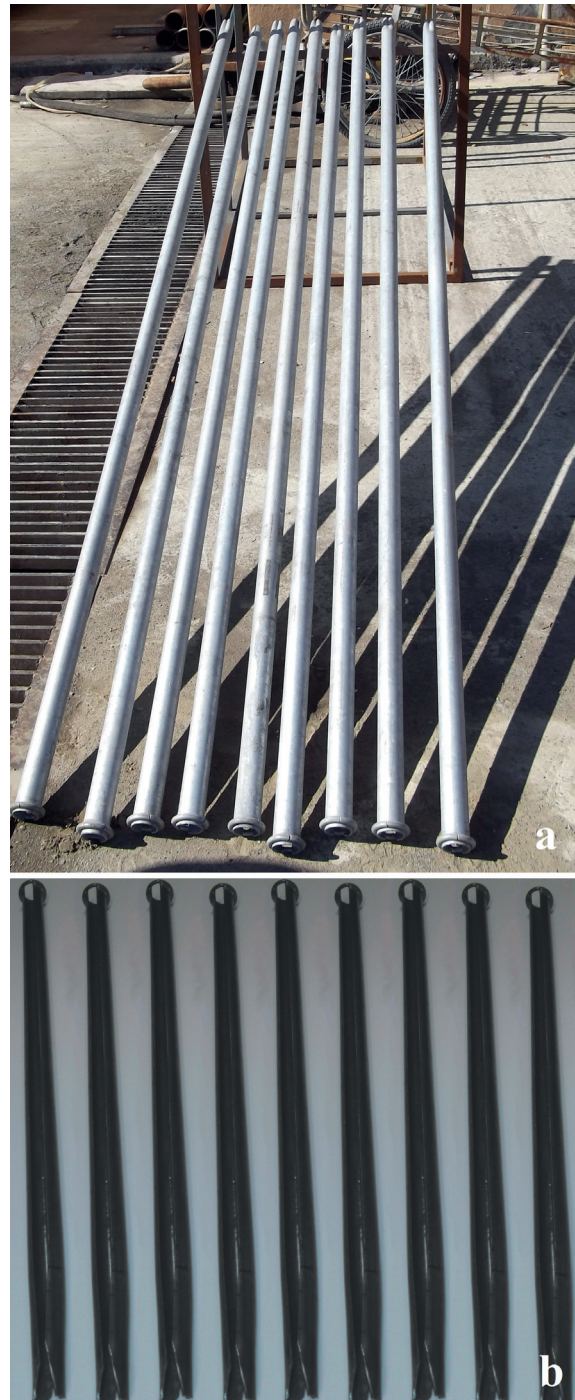


Fig. 6 Rock bolts used in the field tests:
a) split sets with the length of 2.5 m, b) split sets with the length of 1 m

**Table 5** Loads measured from the Pull-out test

($F_1$: load bearing capacity of bolts with 1 m length, $F_{2.5}$: load bearing capacity of bolts with 2.5 m length)

| | Chalcopyrite Ore 1 | | Limestone | | Dacite | |
|---|---|---|---|---|---|---|
| | $F_1$ (kN) | $F_{2.5}$ (kN) | $F_1$ (kN) | $F_{2.5}$ (kN) | $F_1$ (kN) | $F_{2.5}$ (kN) |
| Replicate 1 | 29 | 52 | 25 | 49 | 27 | 61 |
| Replicate 2 | 25 | 56 | 22 | 45 | 30 | 58 |
| Replicate 3 | 26 | 50 | 22 | 46 | 31 | 54 |
| Mean | 27 | 53 | 23 | 47 | 29 | 58 |

**Table 6** Ratio between load bearing capacities of bolts with different lengths of 2.5 m and 1.0 m ($F_{2.5}/F_1$)

| Rock Formation | $F_{2.5}/F_1$ |
|---|---|
| Chalcopyritic Ore | 1.96 |
| Limestone | 2.04 |
| Dacite | 2.00 |
| Numeric Model (Eq. (2)) | 2.05 |

**Table 7** A comparison between experimental results and Eq. (1) for bolts with the length of 2.5 m ($F_p$ = load bearing capacity per one meter length of bolts, $F_{2.5}$ = load bearing capacity of bolts with the length of 2.5 m)

| Rock Formation | $F_p$ (Eq. (1)) | $F_p$ ($F_{2.5}/2.5$ m) |
|---|---|---|
| Chalcopyritic Ore | 22.1 kN | 21.2 kN |
| Limestone | 18.9 kN | 18.8 kN |
| Dacite | 23.8 kN | 23.2 kN |



**Fig. 7** Pull out test: a) bolt pulling, b) loading by using the jack handle

## 3.2 Results
The pull-out test results are given in Tables 5 and 6. According to the pull-out test results, load capacity increased by 2 times when the length increases by 2.5 (2.5/1.0) times. That finding verifies Eqs. (1) and (2) which were derived in accordance with the results of the numerical analyses. Tables 6 and 7 show the similarity between results obtained from experimental and numerical studies.

## 4 Discussions
The numerical part of this study was carried out with the aim of modelling the Pull-out test for determination of the load bearing capacities of friction bolts with different lengths. The frictional load bearing capacity of the bolts was found to increase with an increase in the bolt length. Rate of the increase in the bearing capacity of the friction bolts was investigated within this study. The load bearing capacity of friction bolts was found to be not directly proportional to the lengths of the bolts. It was determined to decreasingly increase with the increase of the bolt length. The stresses at the friction surface was determined to maximize near the tunnel wall side of the drill hole end which was also designated as the critical location for the failure initiation by previous researches [19–22].

Because of the decrease in load bearing values per a friction length, the effect of increase in the bolt length on the frictional load bearing capacity of the split sets was found to be diminished in case of using high bolt lengths. The findings of this study should not be considered to infer that rock bolt length is not needed to be lengthened. For instance, rock bolts should have enough length to support the plastic zone around tunnels by being inserted in the elastic zone. Besides, the length of the bolt in the elastic zone should be high enough for being able to bear the plastic zone load [23–28]. The needed bolt length depends on various parameters like tunnel cross-section shape and size, in situ stress distribution and rock mass quality. The aim of this study was only to investigate frictional load bearing capacity variations of the split sets with the change in its length parameter.

Since the increase in bolt length causes also increases in the stresses induced in the bolt steel material, the steel failure becomes possible instead of the sliding at the friction surface. The increase in the bolt length sometimes has not a positive effect on the load capacity, because the strength of the bolt steel material can make limitations in case of using high bolt lengths [29–32].

The maximum bolt length was 5 m in this study. For the split set type friction bolts, 5 m is significantly over the widely used lengths. The maximum load capacity of the steel tube is typically about 75 kN. Generally, 3 meters length is enough for steel material failure in pull-out tests of the split sets. In addition to the possible steel failure, high bolt lengths are not used in the split set applications due to the buckling during the insertion. To eliminate this problem, bolt lengths are generally smaller than 3 m in applications [33–35]. Therefore, the bolt length variations interval analyzed within this study can be assessed to be enough wide in terms of investigating differences in the frictional load capacity of the split sets.

The friction coefficient changes the stress distribution in the steel material and critical bolt length for the steel failure [36–38]. The relation between the frictional load bearing capacity and bolt length variations was determined to be same for different friction coefficient values for the rock and bolt contact. Therefore, it was assessed that there is no need to use the friction coefficient parameter in Eqs. (1) and (2). The equations suggested in this study are valid for different friction conditions. The results obtained from experimental and numerical studies were quite similar as seen from the ratio of $F_{2.5}/F_1$ which was nearly same in both analyses.

## 5 Conclusions

The frictional load bearing capacity variations of the split sets with the change in the bolt length parameter were investigated within this study. The load bearing capacity per a friction length was found to decrease with an increase in the length of the bolt shank. Therefore, the load bearing capacity was found to be not directly proportional to the length. According to the results of both experimental and numerical analyses, Eqs. (1) and (2) can be used to calculate the change of the load bearing capacity of the friction bolts.

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