Madencilik - Mining, 2021, 60(3), 131-135

BİLİMSEL MADENCİLİK DERGİSİ
SCIENTIFIC MINING JOURNAL

TMMOB Maden Mühendisleri Odası Yayını / The Publication of the Chamber of Mining Engineers of Turkey

www.mining.org.tr

Original Research / Orijinal Araştırma

Improving performances of friction rock bolts by using new spring plates

Yeni yaylı plaka kullanımı ile sürtünmeli kaya saplamaları performanslarının iyileştirilmesi

Eren Kömürlü[a,*]

[a] *Giresun Üniversitesi, İnşaat Mühendisliği Bölümü, Giresun, Türkiye*

Geliş - Received: 20 Mart - March 2021 ▪ *Kabul - Accepted:* 31 Mayıs - May 2021

A B S T R A C T

In this study, a new spring plate was designed and investigated for its usability with the split set type friction bolts. According to the results of this study, remarkable active support pressures can be practically supplied by compression of the new spring plate during the insertion of the split sets. In addition to easy supply of the active support pressure owing to the insertion of the bolts, the energy absorption capacity can be highly improved by use of the new spring plate. Furthermore, the new plate design is remarkably advantageous against the nonaxial loading condition which is very wide in the bolted rock masses.

Keywords: Split sets, Friction rock bolts, Plate design, Energy absorption capacity, Spring plates.

Introduction

Rock bolts which are widely used to supply stability of rock engineering excavations can be classified in accordance with different parameters such as grout usage (grouted or friction bolts), grout type (cement, resin, etc.), shank body material (steel, polymeric composites, etc.), pre-tensioning properties (active, passive), energy absorption capacities (energy-absorbing bolts and others) and etc. (Li et al., 2014, Wang et al., 2019, Ranjbarnia et al., 2016, Komurlu and Kesimal, 2013).

The most popular and economical friction bolts, split sets are passive rock bolts which supply support pressures owing to deformations of rock masses. The split sets are quite simple and only consist of a tube body and a matching plate part. As a split set is installed by pushing into a drill hole with slightly lower diameter than that of its body, the radial spring force is generated by the compression of the tube with the cross-section of C shape, which provides the frictional anchorage. Because of no waiting for curing reactions of grout materials, the split sets are able to immediately supply support pressures as they are inserted. Because of various reasons like the corrosion problem of steel, stress relaxation of the compressed tubes in drill holes, service lifetimes of friction type rock bolts are not generally more than several months (Komurlu and Kesimal, 2015; Nicholson and Hadjigeorgiou, 2018; Hassell and Villaescusa, 2005). The split sets are widely used in mining openings for short-term purposes.

In this study, a new plate with quadruplet springs was designed and tested to assess whether a proper active support pressure can be supplied by its use. It is able to induce active support pressures by the compression of the spring plate during the insertion of the split-sets. In addition to the active support pressure supplied without a need for rock mass deformation, it was aimed to improve energy absorption capacities of the bolts by using the newly designed spring plate with a significant deformation capacity. Unless the plate part or the bolt shank is failed, friction bolts generally have ductile support reactions due to the sliding in the drill-hole. In terms of supplying good energy absorption capacities and proper support reactions, it is advantageous to have high displacement limits while keeping the load bearing capacity. Especially, the deformability property of rock bolts is a key parameter of support designs for various rock masses such as those with burst, squeezing and swelling problems (Wu et al., 2019; Komurlu et al., 2017; Aksoy et al., 2016). Improvement of the deformability property makes a better energy absorption capacity of rock bolts (Zhigang et al., 2017; Stacey, 2016; Komurlu and Kesimal, 2017). In this study, a new spring plate was designed and investigated to assess how effective it is for improving the energy absorption capacity. An important anchorage mechanism of the rock bolts can be supplied by the plate parts. Therefore, plates should be tightly contacted to the rock surface.

In many times, angles between the plate and drill holes are not perpendicular in rock bolting applications. Because of having devi-

*Corresponding author/Sorumlu yazar: ekomurlu@giresun.edu.tr * https://orcid.org/0000-0002-2123-7678

https://doi.org/10.30797/madencilik.900175

ations from the perpendicularity of angle between rock bolt shanks and plates, loads on plate stabilizer elements like nuts or welded assemblies are not applied as uniformly distributed (Figure 1). In the circumstances, load bearing capacities of rock bolts can be notably decreased by a locally concentrated stresses at the plate part. Ability to increase in the uniformity of the stress distribution at the plate part by use of the new spring plate was also investigated as detailed in the following title.

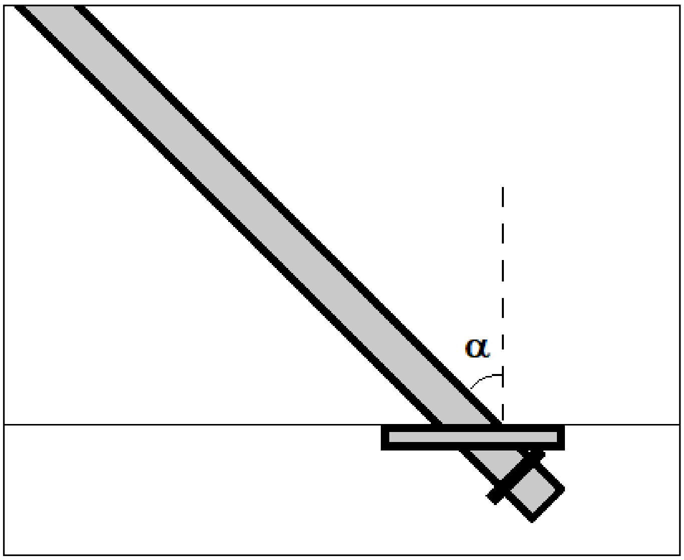

Figure 1. *Inclination angle of the bolt shank (a)*

1. Methodology

Steel compression springs with the outerside diameter (D_o) of 45 mm, inside diameter (D_i) of 29 mm, wire diameter (D_w) of 8 mm, free height of (H_f) 66 mm and pitch size (S_p) of 17 mm were used between two steel plates with welded hoops for holding them (Figure 2). The compression springs were preferred to have closed and ground ends to supply a good contact to the flat surfaces of the plates. To evaluate its load bearing and energy absorption capacities, the new spring plate was tested under an electric motor press equipment (Figure 3). Using a Linear Variable Differential Transformer (LVDT) device, the load and displacement graph was obtained and the energy absorption capacity in the unit of Joule (J: N.m) was determined by calculating the area under the load-displacement graph.

Additionally, the spring plate was also used with steel tubes with the outer diameter of 42 mm and one side wall thickness of 3 mm in the pull-out test (Figure 4). Sizes of the steel plates used in this study are 150 mm x 150 mm x 15 mm, and 4 springs were used between them. To compare with results obtained from the spring plate, a flat plate having the same sizes of those used with the springs was also tested in the pull-out test. The steel tubes with drilled front sides were fixed to the bottom of the pull-out test equipment by insertion of steel rods with the diameter of 11 mm (Figure 5). All the steel tubes used in this study have same welded ring ends touching on the plates to be loaded in the pull-out test. To investigate the effect of a angle (inclination angle of the bolt shank) on the maximum load values (F_{max}), 0°, 14° and 25° a conditions were tested for both flat plate and spring plate uses (Figures 6 and 7). In the pull-out tests, F_{max} values were measured as the load level for failure of the welded rings which are the plate stabilizer elements in this study.

Figure 2. *Size parameters of springs (a), springs (b) and the spring plate (c) used in this study*

Figure 3. *Compression test of the spring plate*

Figure 4. *The pull-out test equipment in this study*

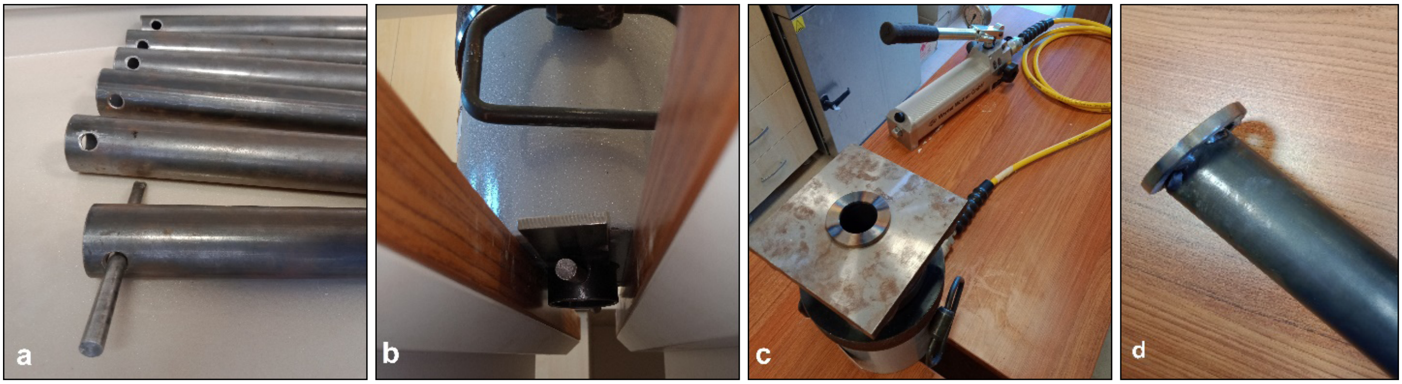

Figure 5. *Front part drills of the bolt shanks (a), fixing the shank using rods below the pull-out test equipment (b), top-view of the loading setup (c), failure of welded stabilizer rings (d)*

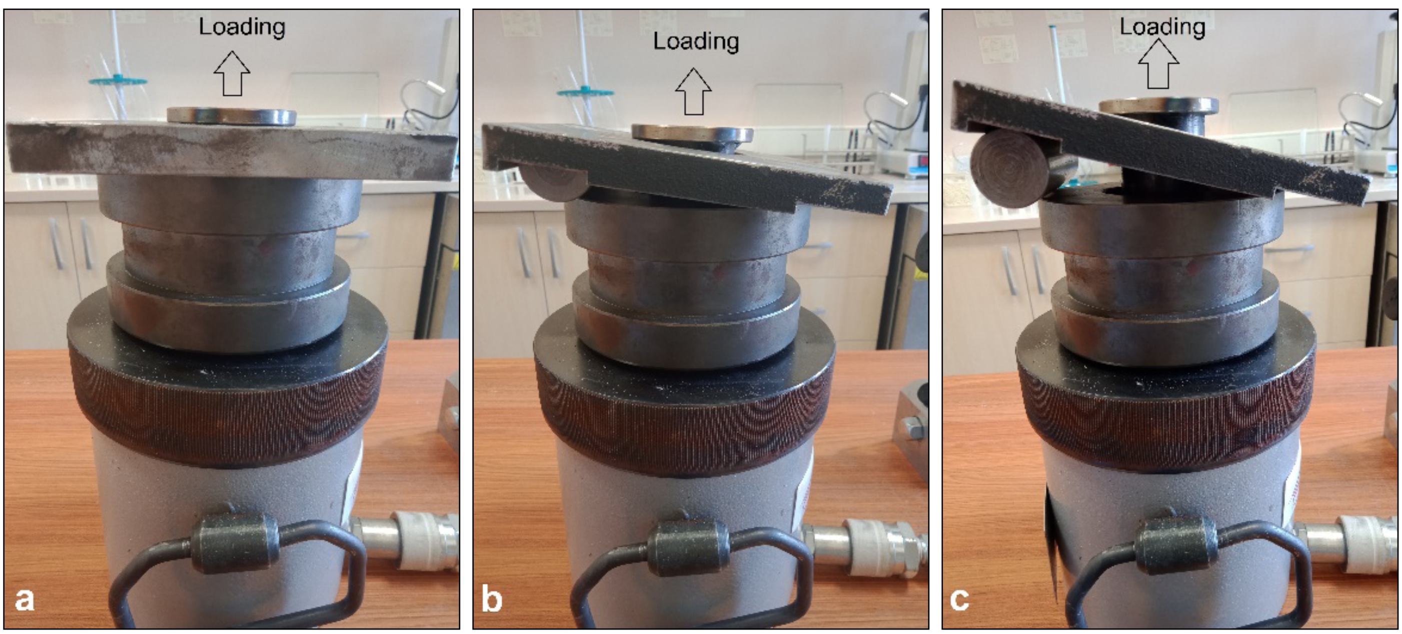

Figure 6. *The pull tests of tubes with flat plates in cases of a:0° (a), a=14° (b) and a=25° (c)*

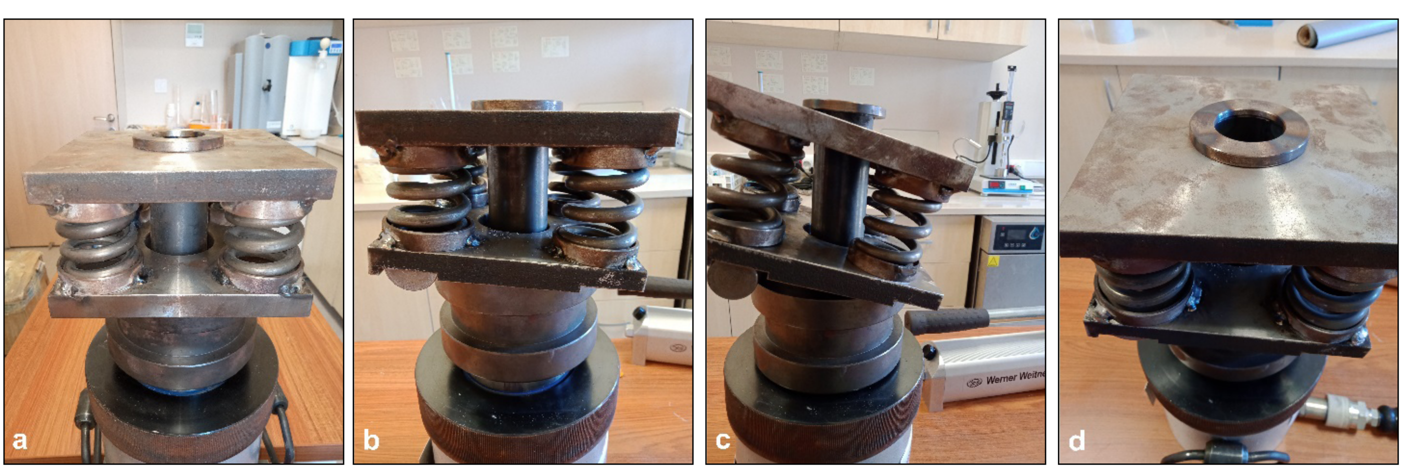

Figure 7. *The pull tests of tubes with spring plates in cases of a:0° (a), a=14° (b) and a=25° (c and d)*

2. Results and Discussions

Load-displacement data obtained from the compression test is given in Table 1. As seen in Figure 8, the load-displacement graph inclination and the stiffness of the springs were found to increase with increasing load level under the compression test continued to the deformation level of 16 mm. That compression was assessed to be in the elastic interval since the 16 mm deformed springs were completely turned their initial free length. According to the area under the load-displacement graph, the spring plate was determined to supply an energy absorption capacity of 190 J at the compression level of 16 mm (J: N.m). It is possible to have higher energy absorption capacities in case of further deformations of the investigated compression springs.

It was determined that 24 kN active support load can be supplied due to the spring plate compression for 16 mm. The steel split sets widely used in the mining industry have a typical tensile load bearing capacity of steel body interval between 70 kN and 90 kN for the uncorroded case. Considering the load bearing capacities of the steel shank bodies of the typical split sets, the active support load of 24 kN can supply 30-40% of the maximum support pressure without a need for rock mass convergences (Thompson and Villaescusa 2014; Salcher and Bertuzzi 2018; Komurlu and Kesimal, 2015; Komurlu et al., 2014). The active support pressure is a remarkable advantage for rock bolts in terms of limitations in the convergences and loosening of the jointed rock masses (Ranjbarnia et al., 2016; Wang et al., 2019; Das et al., 2020) The split-sets are a typical friction type passive rock bolts. It is a novelty for the split-sets to practically supply active support pressure by using the spring plates. This study is aimed to make contributions for further studies on using various spring plate designs for different active support pressure properties, improved load bearing and energy absorption capacities.

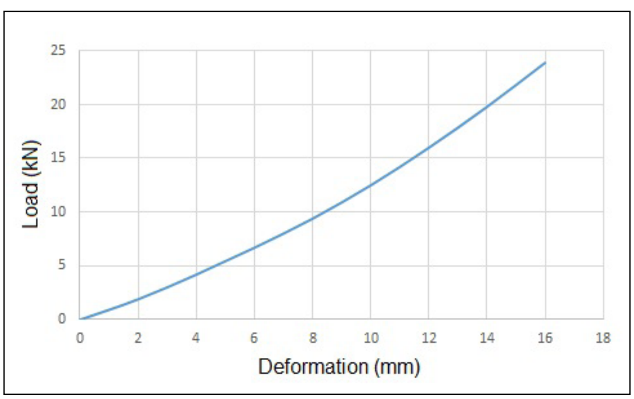

Figure 8. *Load deformation relation obtained from the compression test*

Table 1. *Compression test results of the spring plate*

Deformation (mm)	Load (kN)
2	1.9
4	4.2
6	6.7
8	9.4
10	12.5
12	16.0
14	19.8
16	23.9

The ordinary plates have low energy absorption capacities especially in the non-axial loading case. As it is confirmed by the results obtained from this study, it is common to see early failures of plate stabilizer elements like nuts and welded rings due to the concentrated and non-uniform load distribution (Zhang et al., 2019; Li, 2010; Kang et al., 2015). Even in the non-axial loading condition, the spring plate was determined to have proper contact to the ring. One of the plates which the springs are held between can have proper contact to the stabilizer ring while the other one can be rotated in accordance with the surface angle (Figure 7). The variability in directions of its two plate pieces contributes to the uniformity of the stress distribution at the plate fixing (stabilizer) part.

The pull test results for flat and spring plates are given in Table 2. It was determined that use of the spring plate slightly improves the F_{max} values for the axial loading case. According to the results obtained from this study, load bearing capacity (F_{max}) of the rock bolt plates without compression springs notably decreased with increasing a angle values. As seen in Table 2, the flat plates caused 37% and 53% loss in the F_{max} values for the cases of a=14° and a=25°, respectively. The spring plate was found to significantly minimize the affect of the non-axiality that the losses in the F_{max} values were respectively 10% and 23% for the cases of a=14° and a=25°. An improvement in the energy absorption capacity of the plate part can be supplied by the deformability property of the compression springs. Additionally, the increase in the F_{max} values can be noted as an important advantage to have improved energy absorption capacity levels (He et al., 2014; Li et al., 2014; Villaescusa et al., 2014; Yang et al., 2019). Further site studies will be highly beneficial for better understand the support properties of the new spring plate design investigated within this laboratory study.

Table 2. *Pull-out test results (R: Replicate, P: flat plates without springs, S: spring plate, 0: a=0°, 14: a=14°, and 25: a=25°, Loss is given as the percentage of F_{max} of P0, NA: loss is not available)*

Parameter	P0	P14	P25	S0	S14	S25
F_{max} of R1 (kN)	28	20	15	31	27	24
F_{max} of R2 (kN)	31	17	15	34	28	23
F_{max} of R3 (kN)	30	19	13	35	25	21
F_{max} in mean (kN)	30	19	14	33	27	23
Loss percentage	0	37%	53%	NA	10%	23%

Conclusion

According to the results obtained from this study, following research findings can be listed as conclusions.

1. Remarkable active support pressures can be supplied by the spring plates.

2. Energy absorption capacity of the rock bolt plate parts can be improved by using spring plates.

3. The spring plates are advantageous against the non-axial loading condition which is very wide in the bolted rock masses.

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