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A LABORATORY STUDY ON USE OF SCREW-TYPE FRICTION BOLTS AS NEW SOFT ROCK STABILIZERS

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ABSTRACT

In this study, load bearing capacities of screw bolts as a new friction bolt type was investigated carrying out a series of laboratory studies. New screw-type friction bolts with sharp threads were inserted into holes drilled in various soft rocks by applying rotation. Screw bolts and split sets inserted in different soft rock types were investigated to comparatively evaluate their load bearing capacity values. According to the results obtained from this study, new screw bolts were found to supply better load bearing capacity values than those of the split sets. Although the split sets are quite popular friction bolts used in rock engineering, they have significant disadvantages resulting from their poor anchorage performances in soft rocks. By making grooves on drill hole contact surfaces, increased coefficient of friction and load bearing capacity values can be supplied by new screw bolts which were found to be advantageous for using in soft rocks.

Keywords: Friction bolts; Openings in soft rocks; Reinforcing soft rocks; Rock bolts; Screw bolts.

1 INTRODUCTION

Rock bolts which are widely used to reinforce mining and civil 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. [1-6]. Grouted rock bolts have grout bonds between the rock and bolt surfaces. On the other hand, friction bolts have the ability of bearing load without using grout materials. The friction type rock bolts supply support pressure by the friction forces at the contact of the bolt shanks and rock surfaces of the drill holes. The most popular and economical friction bolts, split sets are quite simple and only consist of a tube body and a matching plate part.

Load bearing capacities of rock bolts depend on various parameters. No matter how strong the bolt is, the load bearing capacity is limited by the rock strength in poor rock masses. Generally, rock bolts can not supply a good bearing capacity for the stabilization of excavations in soft rocks because of the low anchorage performances in the low strength rock masses. Even if a strong steel shank body is used in soft rock masses, a good bearing capacity can not be generally supplied by bolting as a result of the absence of an enough anchorage capacity [7-9]. Additionally, the watery drilling process can make significant decreases in strength values of the soft rock masses like those with the poor slake durability property. Because the rock strength is a determinative parameter for the friction coefficient of the drill hole and bolt contact, friction bolts like split sets sometimes exhibit undesired load bearing performances in soft rocks [10, 11]. Similarly, grouted rock bolt performances also depend on the rock strength parameter [12, 13]. The main motivation of this study is to design and investigate a new friction bolt to supply improved bearing capacity values in soft rocks.

The newly designed rock bolts have screw-like shanks with sharp threads to improve adherence in drill holes. The screw-like new bolts are inserted into the drill holes by rotating. The screw anchors are also used in soil masses by using no drill hole [14-16]. Considering their usability in rock masses, it is estimated that it is not possible to install screw type new rock bolts without drill holes except for extremely soft rocks. Therefore, the holes must be drilled to insert the screw type new rock bolts into the rock masses. There are two different diameters of screw

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type bolts, which are outer (d_o) and inner diameters (d_i). To make a good coupling, the outer diameter (d_o) of the new rock bolts should be selected higher than the drill hole diameter. However, the inner diameter (d_i) should be selected to be lower than the drill hole diameter for the ease of the insertion. Because of their scratchability, soft rock surfaces can be advantageous in terms of increasing the contact roughness and thus the anchoring performance of the screw threads.

Some physical properties of the new bolts are given in Figure 1. It was aimed to use screw bolts to turn the softness of the rock surfaces into an advantage. For the transfer of rock crumbs occurred during installation, the pitch and the thread depth (d_o-d_i) are important physical parameters to be selected enough high in terms of insertion practicality of the new bolt designs. On the other hand, it should be considered for an optimal design that big pitches cause a decrease in the thread number and the adherence performance. As another important requirement, thread crests of the new rock bolts must be sharp to easily make scratches on the soft rock surface and supply an improved adherence in drill holes. Since the screw bolts are inserted by rotation, they can have cornered ends like triangle, square or hexagonal shaped ones to be properly gripped. There are various design parameters for the screw bolts to select a proper reinforcement for a relevant soft rock mass. It should be reminded herein that the screw bolts are investigated only for soft rocks within this study.

Use of no grout material can be assessed to be an important advantage especially because of the ability to start load bearing immediately after the insertion without a need to wait grout curing reactions [17-19]. Screw bolts can have pipe type hollow bodies or solid cross-sections. Since other friction bolts have no solid bodies, screw bolts are estimated to supply significantly higher body strengths than those of the popular hollow body bolts like split sets and swellex types. Within this study, it was investigated to assess whether the screw type new rock bolts are advantageous in terms of providing higher load bearing capacity values in comparison with other friction bolt types. The new screw bolt design details are given in the following section.

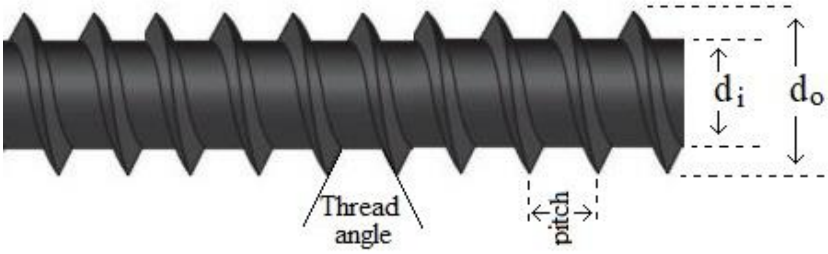

Figure 1. *Some physical properties of screw bolts*

2 MATERIALS AND METHODS

Load bearing performances of the new screw bolts in various soft rock materials were investigated within the laboratory study. In the laboratory tests, tuff, dacitic tuff, sandstone and clayey limestone type four different rocks were used to determine the new bolt performances. Tuff, dacitic tuff, sandstone and clayey limestone samples are soft rocks which have the uniaxial compressive strength (UCS) values of 13 MPa, 18 MPa, 16 MPa and 21 MPa, respectively. The UCS tests were carried out by using rock core specimens with the NX size diameter. The UCS tests were carried out to get an idea about the rock materials used in the bolt anchorage tests. According to the ISRM (2007), all the UCS test specimens were cut to have the height to diameter ratio of 2.5 and were loaded under a compressive strength test press (Figure 2) [20].

The rock materials were also examined by using the geological hammer. All the used rock materials had indentations made by a firm blow with the point of the geological hammer. Additionally, surfaces of all the rock materials tested in this study can be scratched by the pocket knife. According to both UCS test and the geological hammer investigations, rock materials used in this study can be classified as weak rock materials [21-23]. According to the examination with the geologist hammer, the softest one within the tested rocks was practically assessed to be the tuff samples, and the relatively harder one was determined to be the clayey limestone. To illustrate its softness property, Figure 3 shows that it was found able to insert a steel screw with the outer diameter of 8 mm into a tuff block by hand power without making a drill hole.

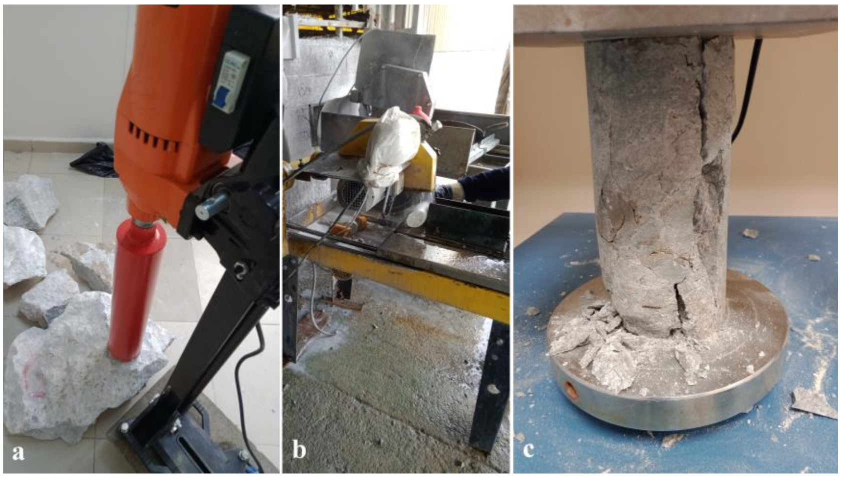

Figure 2. *a) Rock specimen coring, b) core cutting, c) uniaxial compressive strength testing*

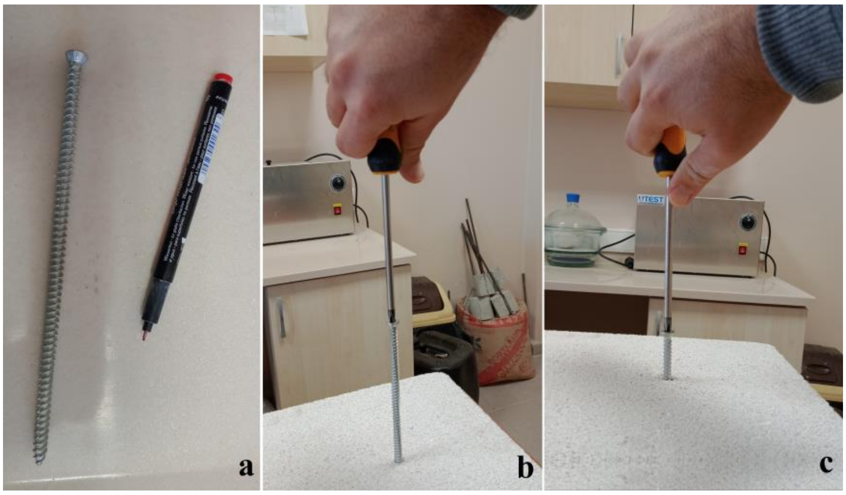

Figure 3. *A small diameter screw insertion by hand*

The clayey limestone, sandstone and tuff blocks were regularly cut blocks from the North-Eastern and Eastern regions of Turkey. On the other hand, dacitic tuff samples had no sawed surfaces and were brought from an underground copper mine in the Black Sea Region of Turkey. Among the dacitic tuff blocks in the mine, relatively regular shape ones were selected and brought to the laboratory to be drilled for the bolt insertion.

Within this experimental study, rock blocks were drilled by using a stand driller machine (Figure 4). For the preparation of screw bolt inserted holes, a drill bit with a diameter of 24 mm was used. In the laboratory tests, length of drill holes was 25 cm. The rock bolts used in the laboratory tests have a length of 60 cm. The 25 cm parts were inserted into the drill holes by the rotation of screw bolts. The contact length in the hole was 25 cm for all rock blocks. The insertion rotation was supplied by an electric machine. To effectively grip the bolt, head parts of the screw bolt specimens were manufactured to have a square-shaped cross section (Figures 5 and 6). To compare their load bearing capacity values with those obtained from the screw bolt specimens, conventional steel split set specimens were also used in the experimental study. Split set tubes with the outside diameter of 39 mm were cut to make an angular front end with 45° cut angle for their insertion into the holes drilled by using a 36 mm diameter bit. Slits were on the longer sides of the tubes with the angular front end. Using an electromechanical loading system, split sets were pushed into drill holes with the length of 25 cm as seen in Figure 7.

To determine the bearing capacities of the bolts, the pull-out test which is a famous anchorage test was carried out. The aim of the pull-out test is to determine the bearing capacities of rock bolts under the axial loading condition [24-26]. In the pull-out test, screw bolts were held from the double nuts mounted at the specially treated back ends of the shanks and pulled by the hydraulic jack of the test equipment (Figure 8). In addition to the nut holding mechanism, the pull-out test equipment jaws strongly gripped the shanks. The outer (d_o) and inner diameters (d_i) of the lab scale screw bolts were 28 mm and 20 mm, respectively. The pitch size of the lab specimens was 4 mm. In the pull-out test of split set samples, trimmed rings were assembled to hold the cut tubes. As seen in Figure 9, steel rods were driven in drilled holes of the tubes to fix the rings. The rings at the split set ends were contacted on the drilled plate during the loading (Figure 9). Drill hole diameter in rock blocks to split set tubes' diameter ratio was about 0.92, which falls within the typical range for split set applications [27-29].

Figure 4. *Rock block drilling*

3 RESULTS AND DISCUSSIONS

The pull-out test results obtained from the laboratory study are given in Table 1. According to results, screw bolts were found to have notably higher load bearing capacities in comparison with the split set samples. Screw bolts were evaluated to supply approximately 2.5 times higher bearing capacity than those of the split sets for the same contact length in drill holes. It was determined that screw bolts are much more advantageous to supply a proper load bearing capacity performance compared to the split sets.

Figure 5. *a) and b) thread designs of laboratory specimens, c) a shown of the square-shaped end of the screw bolts, d) a photo of screw bolt insertion in the laboratory study*

Figure 6. *Square-shaped ends and threaded parts to be fitted with nuts*

Table 1. *Pull-out test results obtained from the laboratory study (F_{max}: Maximum load, SN: Number of specimens, SD: Standard deviation)*

Rock type	Screw bolt samples			Split set samples		
	Mean F_{max} (kN)	SN	SD (kN)	Mean F_{max} (kN)	SN	SD (kN)
Sandstone	29	5	3	11	5	2
Tuff	35	4	2	13	4	1
Dacitic tuff	32	5	4	14	5	3
Clayey limestone	40	5	4	16	5	2

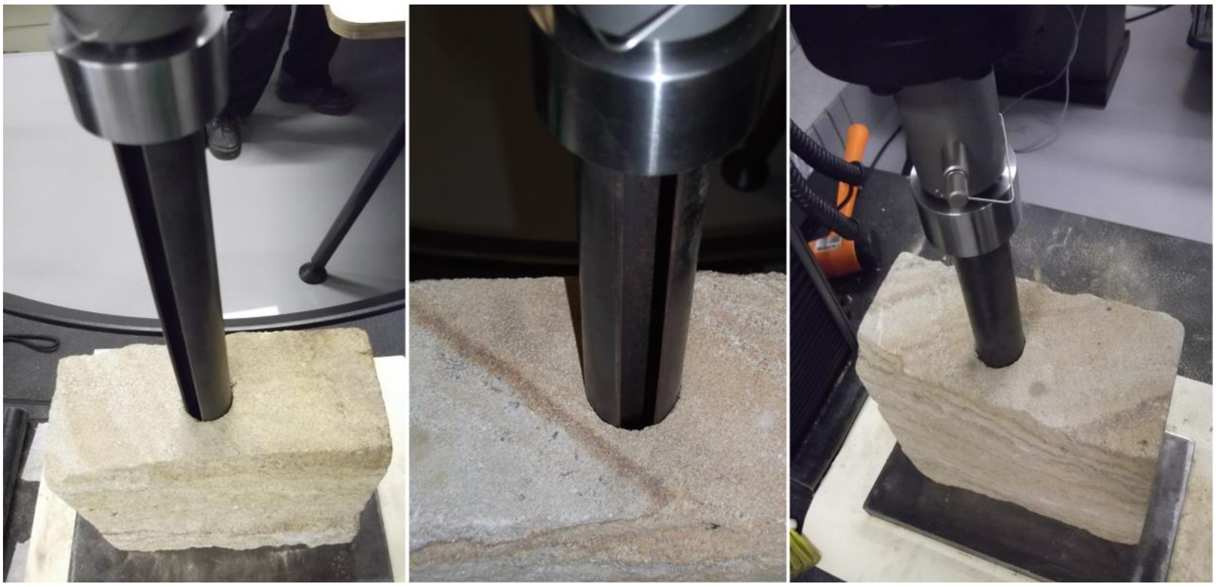

Figure 7. *Insertion of split sets in the laboratory study*

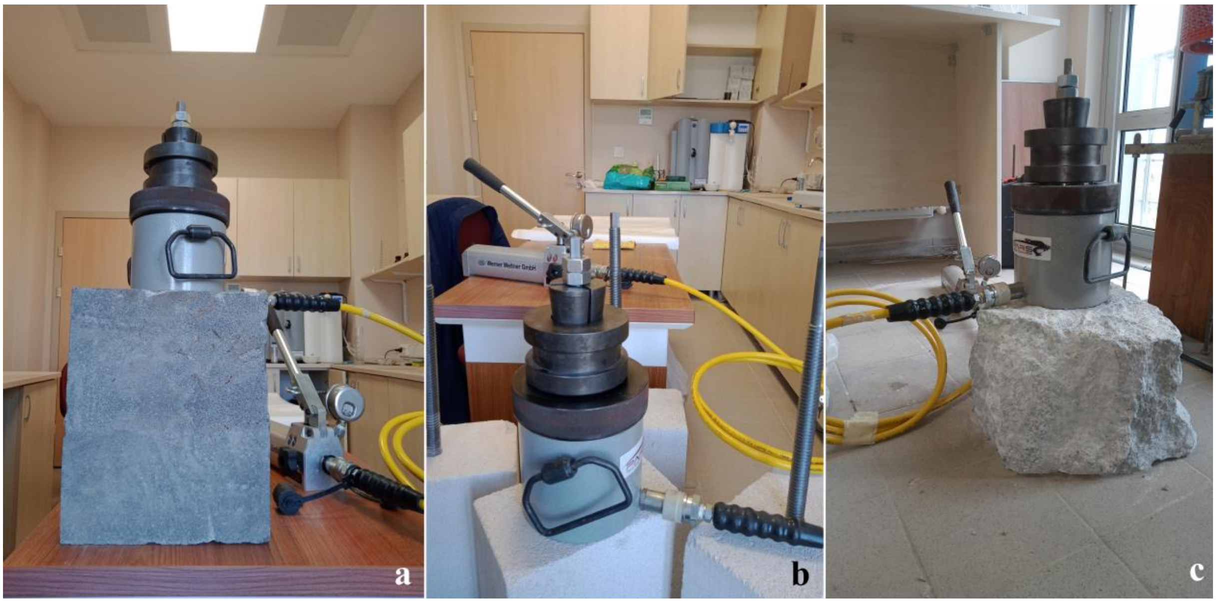

Figure 8. *Some photos from pull-out tests of screw bolt specimens used in the laboratory study*

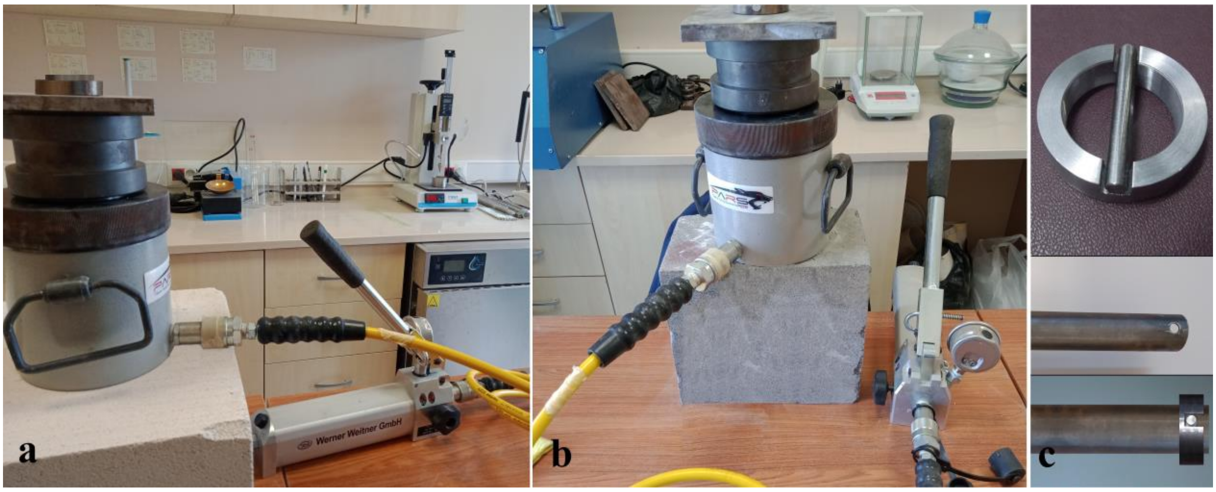

Figure 9. *Some photos from pull-out tests of split sets (a, b), split set tubes' holding ring mechanism (c)*

This study does not include a field-sized bolt design investigation. It is a preliminary one carried out by using an early laboratory-scale screw bolt design. For an improvement of its support performance, new thread and drill designs can be investigated within further studies. The screw bolts were investigated for soft rocks in this study. Within the future studies, special screw designs can be also investigated for a potential use of the new bolts for mid strength rocks. In all the load bearing capacity tests, bolts slid in the rock blocks as the maximum load level is achieved. It can be aimed to design the screw threads for the purpose of increase in the bearing capacity to a level which makes the failure of the body steel.

Use of a long bolt can be an upcoming study topic to make various thread designs in screw bolt applications. The designs of screw threads should be examined in detail for the installation of long-dimensional rock screws. It is estimated that the screw type friction bolt lengths can be limited because of possible high frictions during the installation. In this regard, different pitches, thread angles, thread depths and some other details like crest sharpness and abrasion properties can be investigated in further analyses on the insertion practicality. One of the significant targets in the upcoming designs is thought to be decreasing insertion frictions while improving the load bearing capacity values of the new screw bolts.

In case of low adherence performances in soft rocks, split sets reach their bearing capacity values which are far from the load levels to make the body failure [30-32]. Even if a good adhesion is supplied, the failure of the steel split set tube body occurs at typical load levels of 60 kN - 70 kN [33-36]. Because of the quite limited body bearing capacity values for the tube failure, split sets can not supply the load bearing capacities and support pressures obtained from the screw bolts with the solid cross-section. As a result of their relatively low support pressures, the split sets are disadvantageous to work well in the poor soft rock masses [37-39]. In this study, the bearing capacity values of screw bolts in various soft rocks were remarkably higher than those of the split sets.

Due to the stress relaxation, split sets can have decreases in the normal stress values acting on the friction surface. It is a well-known fact that friction capacities of the split sets worsen depending on time [40-43]. The stress relaxation can be briefly defined as the decrease in the stress values of a material kept under a constant strain. The stress relaxation is a cause for bearing capacity losses of the split set tubes which are compressed and kept at a constant diametric strain in drill holes. Split sets have short service lifetimes which are usually limited to a few months. On the other hand, the screw bolt is a new candidate to make bettered service lifetimes in comparison with those of other friction bolts. It is thought that screw bolts may have relatively longer service times due to their relatively thick body structure. In future studies, effective service lifetimes of the screw bolts can be examined as another important topic to understand the long term support properties of the new rock bolt. The use of hard and corrosion resistant surface coatings for screw bolts can also be another topic of further investigations. Various types of rock bolts have been improved after they were firstly proposed, in consequence of different studies. Similarly, screw bolts are believed to be made more effective with new studies on its use.

Drill bit diameter is an important topic for rock bolting performances. Weak rock masses can be damaged during the wet drilling process. Especially, the preference of large hole diameters increases this damage and can cause soft rock masses to be disturbed [44-46]. It should be reminded herein that this study was particularly carried out for soft rock masses which can have notable strength losses due to the drilling processes. As seen in Figure 10 which is a photo taken from the mine where the dacitic tuff blocks were brought from, the rock mass around drill holes becomes fragmental by hand after the watery drilling process because of poor slake durability and soft surface properties of the dacitic tuff material. Use of the screw bolts is also advantageous because of using relatively low drill diameters. For instance, it was determined that a notably higher load bearing capacity can be supplied by the screw bolts inserted into the holes with 24 mm drill diameter in comparison with the 36 mm drill diameter use in the split set applications. Use of relatively small diameter drill holes makes an advantage to decrease strength losses of soft rock masses.

Figure 10. *A shown of the dacitic tuff formation: a drill hole (a) and its fragmentation by hand (b)*

To deal about costs, it can be noted that the price of shanks of the screw bolts with the outside diameter of 28 mm is 7 USD per one meter length. Adding the price of the plate part, the total cost for a 1 meter length bolt is about 10.5 USD. The cost is approximately 17.5 USD per a bolt with the length of 2 m. It should be noted herein that the prices given above are calculated in consideration of the costs paid in 2023 within this study. It is foreseen that the costs can be significantly reduced for the systematic production of a large number of screw bolts in future. The typical price interval for a commercial split set with the length of 2 m is 8 USD-10 USD per a bolt. Although screw bolts may seem expensive at the first glance, they can be considered affordable due to the advantage of their high bearing capacity. Screw bolts with the solid cross-section were investigated within this study. To decrease the material consumption and the overall bolting costs, hollow body screw bolts can be also investigated within further studies. Screw type new friction bolts are open for very different and novel investigations to better understand their anchorage properties and improve their support performances.

4 CONCLUSION

Screw bolts were investigated as a new friction type rock bolt specimens within this laboratory scale study. Sharp threads of screw bolts provide rough friction surfaces and good adherence properties by scratching the drill hole walls and creating grooves on the soft rock surface. According to the findings, it was found that screw bolts can be used to have an improved load bearing capacity and support performance in soft rocks compared to typical friction bolts like split sets. Because this study is an early one, further investigations and site scale tests will be highly beneficial to better understand the support properties of the novel screw bolts for making new and highly effective designs. The new screw bolts were found to be advantageous to reinforce soft rocks and have a good potential to become a popular friction bolt type in rock engineering.

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