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Strength testing of rock and ground anchor rods under static and dynamic loads

Various types of anchor rods are commonly used for rock mass and soil reinforcement, produced either as full-section steel rods or tubes with threads along their entire length, which are used for the injection of liquid binders. This paper presents the methodology and sample results of strength tests of self-drilling injection anchor rods with R32 rope threads. Such rods are used both in underground mining and in geoengineering under static and dynamic (impact) loads. The results of tests of injection micropiles with trapezoidal thread diameters in the range of T51–T111 mm, used mainly in geoengineering, are provided as well. This paper also presents the basic requirements for the fatigue loading of nails and injection micropiles used in geoengineering, based on standards and the European Assessment Document (EAD), applicable in the European Union.

Key words: *rock bolts, soil nails, injection micropiles, resistance to static and dynamic load, fatigue tests*

1. INTRODUCTION

Various types of anchor rods are commonly used for rock mass and soil reinforcement, produced either as full-section steel rods or tubes with threads along their entire length, which are used for the injection of liquid binders. The increase in deep mine outputs consequently entails the growing significance of rock bolting, performed primarily in order to reinforce the rock mass and increase its self-supporting capacity. Rock bolt support is not only used under the conditions of dynamic loads generated by rock mass tremors and rock bursts [1], but also by dynamic impacts of the means of transport [2]. Anchors are mainly exposed to dynamic tensile impact [3, 4] and shear [5] during rock mass tremors. The economic factor also plays a significant role in the increasing popularity of rock bolting, as this form of support is less expensive compared to steel arch support systems and more convenient from the perspective of transportation. Modern anchors are characterized by great resistance to not only static loads, but also dynamic impact loads. Requirements for the performance of geotechnical works are included in the standards for nails [6] and micropiles [7], which are mainly used for soil strengthening [8–10], foundation of building structures and tunnels stabilization [11]. Therefore, the anchor rods, nuts, coupling sleeves and other elements, constituting the complete reinforcement system, are produced using steel materials with high mechanical properties confirmed through strength testing, primarily under static and fatigue loading. This paper presents the methodology and sample results of strength tests of self-drilling injection anchor rods, used both in underground mining and in geoengineering, under static and dynamic impact loading. The results of static strength tests of injection micropiles, used primarily in geoengineering, are provided as well. This paper also presents the basic requirements for the fatigue loading of nails and injection micropiles used in geoengineering, based on standards and the European Assessment Document (EAD) [12, 13], applicable in the European Union.

2. TEST METHODOLOGY

2.1. Tests under static loading

The basic anchor rod strength parameters are tensile strength R_m, upper R_{eH} and lower R_{eL} yield stress or the proof stress $R_{0.2}$, total percent elongation A_{gt} at maximum force and total percent elongation at break A_t. Tensile testing of the samples of steel used to produce the rods is not reliable. This is primarily due to the fact that the mechanical properties of the steel undergo changes during rod production as a result of processing. It is therefore necessary to subject the end product, i.e. the anchor rod, to tensile testing, which is defined in standard PN-EN ISO 6892-1 [14]. The results of such studies, although carried out under slightly different conditions, are presented in the work [15].

Tests of such rods, as well as of rods coupled by means of couplers, are conducted in a static testing machine with a maximum tensile force of 5000 kN (accuracy class 1). Figure 1 shows a schematic of a static test. The tested anchor rod (3) is mounted between the machine crossbeams and locked on both sides by means of two nuts (2). The force measurement is carried out by force sensor (1) mounted on the fixed crossbeam and the measurement of the displacement is carried out with the use of a line sensor (4) attached to the movable crossbeam to which the force F_s is applied. The initial measurement length L_o is typically 1000 mm. The test consists in loading the tested rod with a tensile force F_s until rupture. The tensile speed is determined on the basis of the stress increase rate (method B in the PN-EN ISO 6892-1 [14]), that is 6–60 $MPa \cdot s^{-1}$. During the test, the loading force F_s and the elongation of the rod ΔL are recorded.

The loading force and rod elongation are recorded during the test. The rod strength parameters are determined using software developed at the GIG Laboratory of Mechanical Devices Testing, based on standard PN-EN ISO 6892-1 [14]. The software calculated those parameters on the basis of measurement data saved in an ASCII code file and information about the cross-sectional area of tested sample S_o and the initial measurement length L_o. The results are presented in a graphical (tensile diagram) and tabular form.

2.2. Tests under dynamic impact loading

The method for anchor testing under dynamic loading according to standard ASTM D7401-08 [16] consists in the free fall (by gravity) of a ram of a mass m from a given height h onto the anchor rod end (Fig. 2).

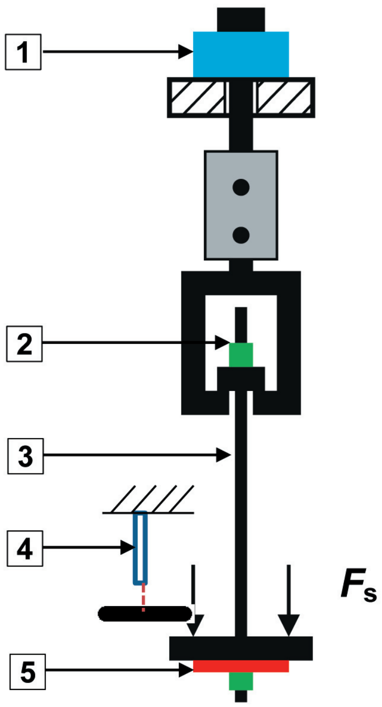

Fig. 1. Load case for an anchor rod under static loading: 1 – force sensor, 2 – anchor nut, 3 – anchor rod, 4 – displacement sensor, 5 – anchor washer

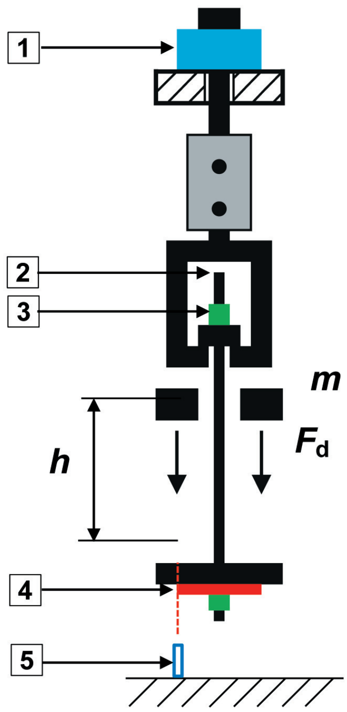

Fig. 2. Load case for an anchor rod under dynamic impact loading: 1 – force sensor; 2 – anchor rod; 3 – anchor nut; 4 – anchor washer; 5 – displacement sensor

The force measurement is carried out by means of a force sensor (1) mounted on the fixed crossbeam and the displacement measurement is carried out by a laser sensor (5) attached to the ground, which measures the displacement of the end of the bold rod.

The test result is deemed positive if the anchor rod transfers a load of an energy and impact velocity declared by the manufacturer without failure.

According to the ASTM D7401-08 standard [16], the initial energy of the impact against the tested rod, corresponding to the potential energy E_p, is calculated using the following formula:

$$E_p = mgh \tag{1}$$

whereas the velocity v of the impact against the tested rod is calculated as follows:

$$v = \sqrt{2gh} \tag{2}$$

where:

- h – ram free fall height [m],
- m – ram mass [kg],
- g – gravitational constant 9.81 [m/s^2].

During testing, the dynamic loading force F_d is measured by means of a strain gauge force sensor (class 0.5), whereas the anchor elongation L_d is measured by a laser sensor (0.1% mm resolution, 0.25% linearity error) with a minimum sampling rate of about f = 10 kHz (as required by standard ASTM D7401-08 [16]). However, the experience of the GIG Laboratory of Mechanical Devices Testing reveals that in order to better capture the character of the dynamic load F_d wave variations, the minimum sampling frequency during testing should equal f = 19.2 kHz. The sensors are connected to a measuring amplifier cooperating with a computer that registers the measurement data. The measuring amplifier is equipped with 24-bit analog-to-digital converters and the measurement data are transferred in a 4-byte form (3 bytes describing the measured value and 1 status byte).

2.3. Tests under dynamic fatigue loading

Anchor tests under dynamic fatigue loading are performed according to [12, 13]. The test is performed in a testing machine with a constant load frequency no greater than 30 Hz, at a constant upper load of 65% of the anchor rod characteristic strength – in this case it is the yield force $F_{p0.2}$, which must first be determined during tensile rod testing under static loading. The range of loads $\Delta F_p = F_{z\max} - F_{z\min}$ must be maintained on a constant level for the entire duration of the test. This corresponds to a stress amplitude of 80 MPa in the nominal cross section of the tested rod. The full test consists of 2 million load cycles. Figure 3 presents the test scheme. The tested anchor rod (3) is fixed between the machine crossbeams and is locked on each side with nuts (1). The axiality of the anchor rod is ensured by the washers (4). Force measurement is performed by means of a strain gauge force sensor (2)

The sample must be tested in a manner precluding secondary oscillations (resonance). It is also important for the sample to be free of filling material. It is essential to maintain a constant vibration amplitude and count the number of cycles during the test. The condition of the tested elements must be inspected after testing – whether cracking or deformation can be observed.

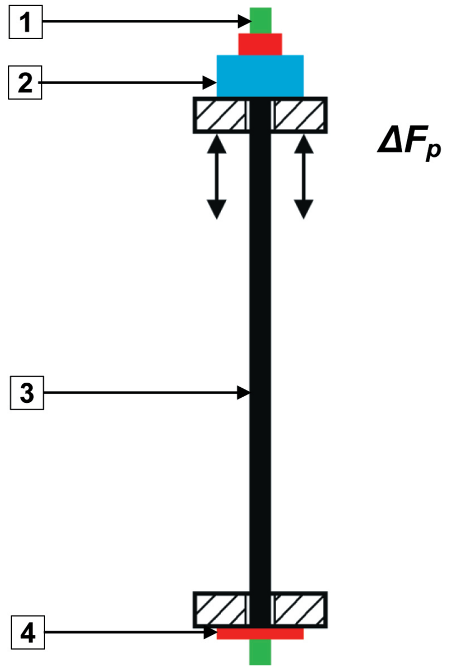

Fig. 3. Load case for an anchor rod under dynamic fatigue loading: 1 – anchor nut, 2 – force sensor, 3 – anchor rod, 4 – anchor washer

3. TEST RESULTS

3.1. Results of tests under static loading

The basic test of an anchor rod under static load is the tensile test. On the basis of this test, the maximum tensile strength R_m, upper R_{eH} and lower R_{eL} yield strength or proof stress $R_{0,2}$, total percent elongation A_{gt} at maximum force and total percent elongation A_t at break are determined.

The tests under static loading encompassed anchor rods with R32 rope threads and injection micropiles with coupling elements (Fig. 4).

Figure 5 presents an example R32 self-drilling rock anchor rod tension chart under static loading.

The anchor rod broke at force F_{smax} = 366 kN.

Figures 6–8 present example T51, T76 and T111 injection micropile rod tension charts under static loading.

An example picture of a steel rod with a coupling sleeve and nuts in a testing machine with a range of up to 5000 kN during tensile testing under static loading is presented in Figure 9. Coupling sleeve allows to connect the anchor rods or micropiles together in order to extend them. Figure 10 demonstrates an anchor rod after a tensile test.

a)

b)

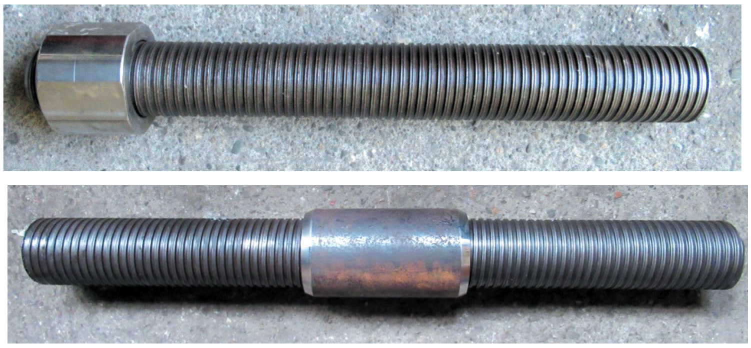

Fig. 4. Example view of an injection micropile with a nut (a) and two sections of an injection micropiles connected with coupling sleeve (b)

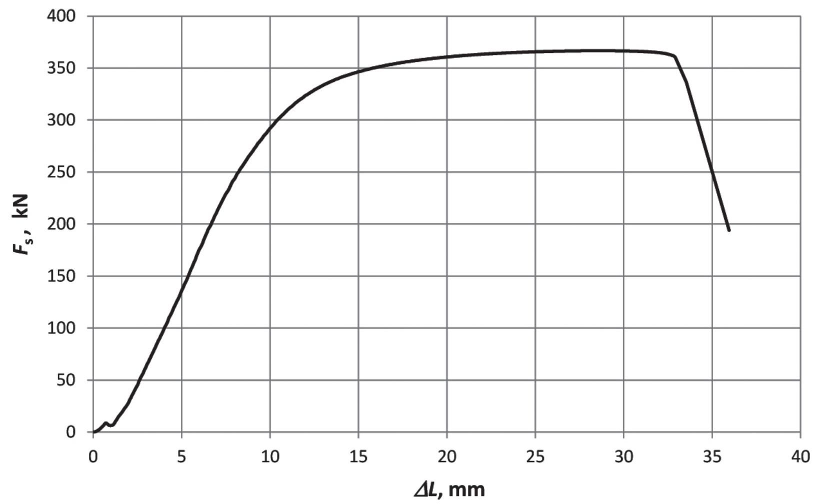

Fig. 5. R32 anchor rod tension chart

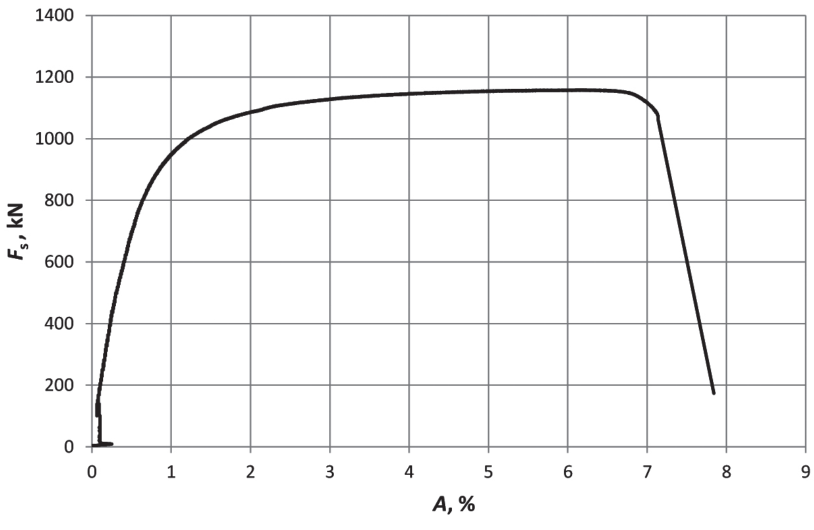

Fig. 6. T51 anchor rod tension chart (F_{smax} = 1159 kN; A_{gt} = 6.2%)

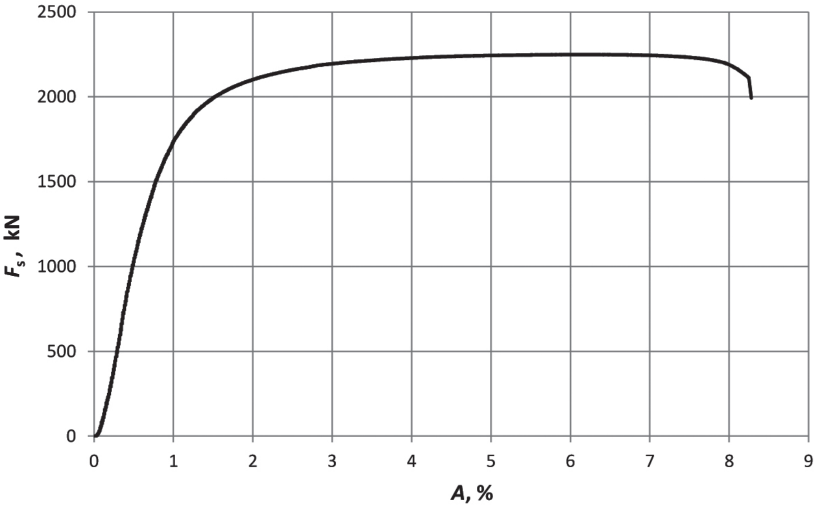

Fig. 7. T76 anchor rod tension chart (F_{smax} = 2250 kN; A_{gt} = 6.0%)

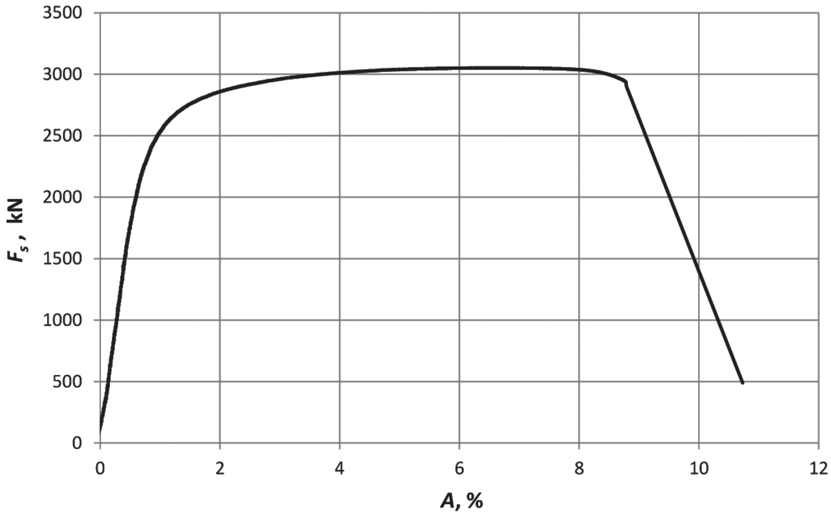

Fig. 8. T111 anchor rod tension chart (F_{smax} = 3052 kN; A_{gt} = 6.4%)

Fig. 9. Rod and coupling sleeve during tensile testing in a testing machine with a range of up to 5000 kN

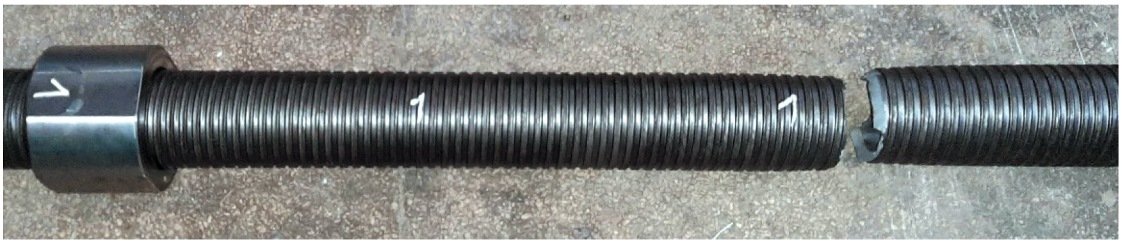

Fig. 10. Ruptured T111 anchor rod after a tensile test

3.2. Results of tests under dynamic impact loading

The tests encompassed self-drilling anchors with R32 rope threads, equipped with steel square washers with dimensions of 200 mm × 200 mm × 12 mm. The tests inspected the anchor rod resistance to loads of an impact energy E_p = 30 kJ and impact velocity of about 5 m/s (test parameters are calculated according to formulas 1 and 2). A ram of a mass m = 1950 kg lowered onto the anchor from a height h = 1560 mm was used during testing; consequently, the anchor was struck with an impact velocity v = 5.5 m/s. An example course of dynamic force F_d as a function of time t obtained during a test is presented in Figure 11.

The anchor transferred the impact load, the energy of which was 30 kJ, without failure. Damped vibrations generated as a result of the ram rebounding from the anchor washer are visible in Figure 11a. Figure 11b presents the first load impulse, when the anchor rod was subjected to the maximum load $F_{d\max}$ = 410 kN and underwent the maximum elongation $L_{d\max}$ = 119 mm.

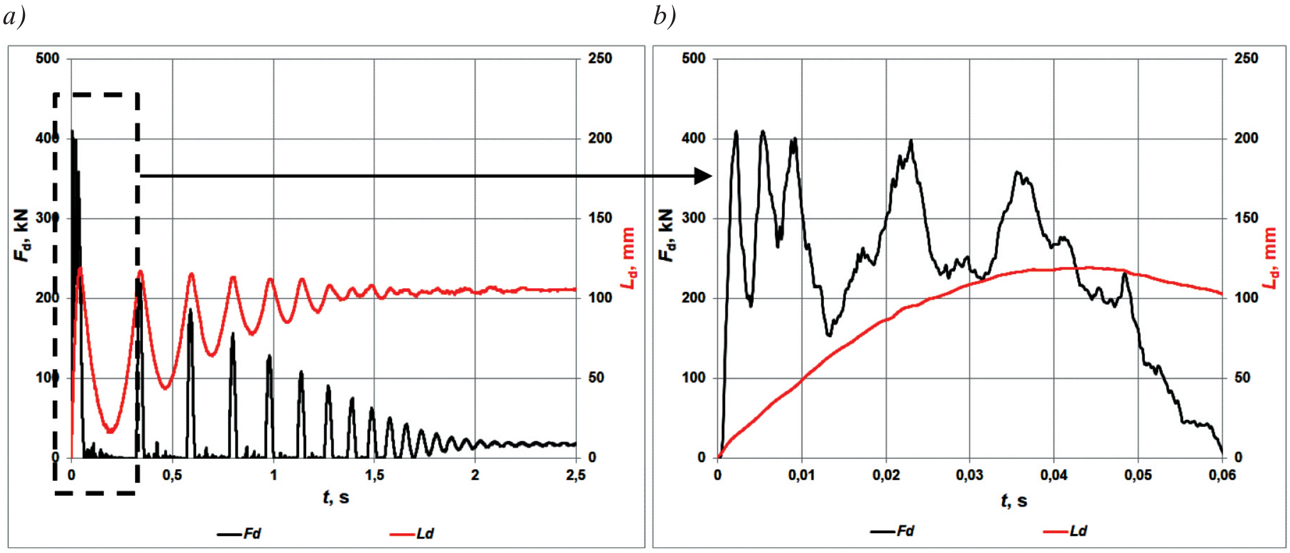

Fig. 11. Example course of dynamic force F_d as a function of time t obtained during a test: a) full course of the test; b) first load impulse

The remaining load impulses, resulting from consecutive, minor collisions of the ram against the anchor washer, result in no plastic deformation of the rod and therefore are not subjected to analysis.

3.3. Results of tests under dynamic fatigue loading

The tests under dynamic fatigue loading encompassed anchor rods with R25 rope threads. The nominal yield force $F_{p0.2}$ is 150 kN, and the nominal cross section area S_o is 300 mm^2. The maximum cyclic load is 65% of $F_{p0.2}$, i.e. 97.5 kN at a load amplitude of 24 kN. The load frequency during testing was over 10 Hz. An example picture of a steel rod in a testing machine during fatigue testing is presented in Figure 12, whereas Figure 13 demonstrates an example chart of cyclic force F_z as a function of time t obtained during a test. After the test, the anchor rod did now show any visible defects or cracks.

Fig. 12. Anchor rod mounted in a fatigue testing machine

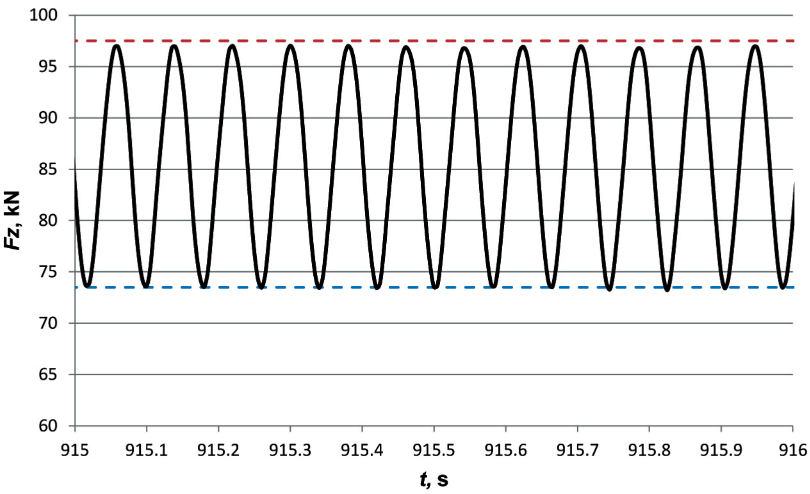

Fig. 13. Example course of cyclic force F_z as a function of time t obtained during a test

4. SUMMARY

The methodologies for testing self-drilling injection anchors with R32 rope threads and injection micropiles with trapezoidal thread diameters in the range of T51–T111 mm presented in this paper factor in the typical operational characteristics of anchors under various conditions of their application. Naturally, these devices are tested under static loading as a standard practice, but the anchor, micropile and soil nail elements may be subjected to various load cases during their operation. Tests of micropiles and soil nails under dynamic fatigue loading are very important to determine their resistance to long-term cyclic loads. However, it seems that, since they find common application in critical infrastructure building stabilisation, it should be considered that they may also be subjected to impact loads induced e.g. by earthquakes or tremors in post-mining areas.

The activities of the Central Mining Institute aim to improve personal safety and work conditions not only in underground mines, but also in post-mining areas, which often struggle with great difficulties in maintaining the stability of embankments, slopes, roads and other elements of structural engineering. For this reason, the micropile and soil nail testing is planned to be expanded with fatigue and impact tests in the future.

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