Development of a double-corrosion-protected self-drilling micropile for the foundation of rockfall protection structures

Matthias J. Rebhan, Hans-Peter Daxer, Franz Tschuchnigg, Roman Marte
Institute of Soil Mechanics, Foundation Engineering and Computational Geotechnics, Graz University of Technology, Graz, Austria

Markus Schuch
ÖBB Infrastruktur AG, Wien, Österreich

ABSTRACT: The construction of protective structures is one of the most important tasks of engineers in the field of natural hazard management. In addition to the often adverse environmental conditions during the installation of these structures, the inspection and the maintenance of such constructions is associated with a high level of effort. This paper presents a newly developed foundation method in the form of a self-drilling, double-corrosion-protected micropile. This component is expected to make a significant contribution in ensuring the durability of protective structures and a sufficient planned service life of more than 30 years. In addition, a brief outlook into the field of loads on protective structures and the suitability and acceptance testing of micropiles is given. Finally, the current status of the further development of the newly conceived micropile and the possibilities that such a system can offer are discussed.

Keywords: micropiles, rockfall protection, corrosion, corrosion protection, foundation.

1 ROCKFALL PROTECTION AND THEIR FOUNDATION

Protective structures such as rockfall barriers are an essential part of the Austrian landscape. Due to the topography, these structures are necessary to protect both traffic routes and habitats. Therefore, micropiles are often used to allow for the foundation and to transfer loads into the subsoil.

1.1 Rockfall protection structures

Rockfall protection structures can be designed in different forms and variants (Bergmeister, 2009). In addition to dam structures (Mölk & Hofmann, 2018), rockfall protection nets are often erected, as shown in Figure 1. These consist of a superstructure formed by posts and a net placed in between. The posts are connected to an appropriate foundation and can also be supplemented - depending on the energy level - by an additional upstream and downstream cable, as shown in Figure 1 left.

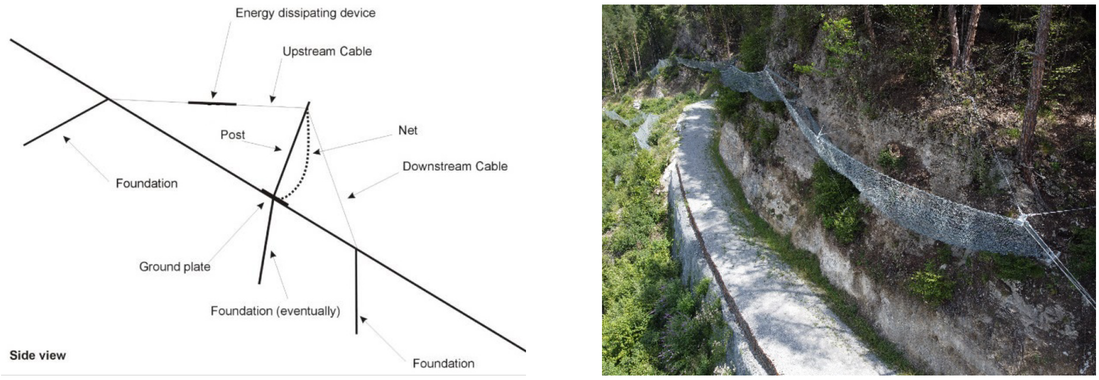

Figure 1. Rockfall protection structures, left: schematic (ETAG 027, 2013), right: rockfall protection next to a railway line.

Shallow foundations can be used for the construction, especially in the area of the ground plate as shown in Figure 1 left. If the subsoil does not have sufficient load-bearing capacity or a shallow foundation cannot be realised economically, micropiles are used. Moreover, these tension elements are usually necessary to transfer the tensile loads from the cables into the subsoil.

1.2 Micropiles as a foundation for protection structures

As already mentioned, the installation of micropiles is necessary for the foundation of protective structures in order to transfer the cable forces into the subsoil and to ensure the load-bearing capacity of the post foundations. Consequently, these are to be installed in the surrounding subsoil along the axis of the protective structure, which means that they are installed in mostly inaccessible areas.

Figure 2. Installation of micropiles, left: hand-guided drilling rig, right: drilling rig attached to an excavator.

The left picture in Figure 2 shows the installation of a solid rod system by means of a cased drilling using a hand-guided drilling rig. Such a construction method has the advantage that it can be used in almost all areas. The disadvantage, however, is that only shallow depths can be reached and that the time required for the installation is correspondingly high.

This is in contrast to the use of drilling rigs or mounted rigs, as shown in Figure 3 right. However, their use requires sufficient space, and unless special equipment such as mobile walking excavators are used, a stable road is necessary. However, it is advantageous that a high daily output can be achieved with such systems, and that both cased drillings and rotary percussive systems can be installed. The latter are particularly suitable for the coarse-grained subsoil often present in the vicinity of protective structures. Despite positive effects related to the bearing capacity, the encapsulation of the (metallic) rod can only be ensured to a limited extent in the case of rotary percussive drilled tension elements. For this reason, a new concept for a durable self-drilling tension element was developed, as described in Chapter 2.

1.3 Corrosion protection measures

In order to ensure durability and the planned service life (ÖNORM B 1997-1-, 2021 & ONR 24810, 2017), appropriate corrosion protection is required. This generally applies to all buildings and structures, although protective structures usually have a shorter service life. A large part of the structural elements can be examined for damage in the course of visual tests and inspections. The foundation elements, however, are installed within the subsoil and therefore cannot be inspected visually. For this reason, attention must be paid to corrosion protection of the tension elements.

Classical corrosion protection measures for tension elements are defined in Austria in the respective system-related regulations (e.g. EN 14199, 2015) and have recently been specified more comprehensively in ÖNORM B 4456 (2021). A distinction is made between single corrosion protection (SCP), double corrosion protection (DCP) and material related corrosion protection (MCP). The former can be further subdivided into sacrificial corrosion allowance (STA), coating corrosion protection (CCP), zinc corrosion protection (ZCP see Figure 3 center) and grout cover protection (GCP see Figure 3 left).

Figure 3. Examples for corrosion protection measures on micropiles, left: single corrosion protection using grout cover protection (GCP), center: single corrosion protection using zinc cover protection (ZCP), right: double corrosion protection (DCP).

Double corrosion protection (DCP see Figure 3 right) refers to a method in which a protective layer is formed around the metallic components by a combination of a cement layer and a corrugated pipe (ÖNORM EN 1537, 2015). Recent investigations on the corrosion behaviour of tension elements and the functional efficiency of corrosion protection methods (DAT, 2022 and Dold, 2021) have shown that the DCP corrosion protection method provides comprehensive protection against the penetration of corrosive environments even under tensile loads. In the case of zinc corrosion protection (ZCP), on the other hand, it has been shown that there is an increased risk of corrosion in the area of damage to the zinc protective layer due to the formation of macro-elements (Nürnberger, 1995). The same applies to the area of cracks within the grout body in the case of grout cover protection (GCP).

2 DOUBLE-CORROSION-PROTECTED SELF DRILLING MICROPILE DCP-SBZ

The brief outline in Chapter 1 shows that the use of micropiles for protective structures is associated with a variety of problems and constraints, ranging from difficulties in installation and erection to issues related to load-bearing capacity and durability.

In the course of a research project (DAT, 2022), possible improvements and optimisation of the foundation of protective structures have been investigated. The results of this project are described below.

2.1 Concept

The basic concept was to develop a permanent and durable tension element that fulfils both the requirements for durability and load-bearing capacity and also offers easy installation to address the aforementioned problems. In the research proposal (DAT, 2022), a micropile system was considered, which consisted of a resin body that is inserted in liquid form into a cased borehole and bonds to the subsoil after hardening.

However, first investigations showed that the production of such resin bodies - with a planned diameter of up to 100 mm - is extremely costly. On the one hand, a cased borehole and the insertion of a protective cage is required. On the other hand, resin in such quantities generates enormous heat, which leads to major problems in terms of curing and the integrity of the grout body. In addition, investigations have shown that resins under tensile loads show a creep rupture related problem (EN ISO 527-1, 2021), which can lead to their partial damage.

For these reasons, this concept was discarded and replaced by the system described in section 2.2.

2.2 Developed micropile system

As already mentioned, resin in the form of a solid body is only suitable to a limited extent for use as a permanent foundation system for protective structures. Nevertheless, the concept of using resins was maintained throughout the research project. To enable its use, two systems were therefore combined in order to emphasise their strengths.

As rotary driven micropiles represent one of the cheapest installation methods in terms of equipment, this system was chosen as a base. This was then supplemented with a corrosion protection in form of a double corrosion protection DCP, as shown in Figure 3 right. However, this could not be achieved by using a cement-filled corrugated pipe, as it would not withstand the impact and abrasiveness due to the rotary percussive installation process. Consequently, the cement was replaced by a resin body as shown in Figure 4.

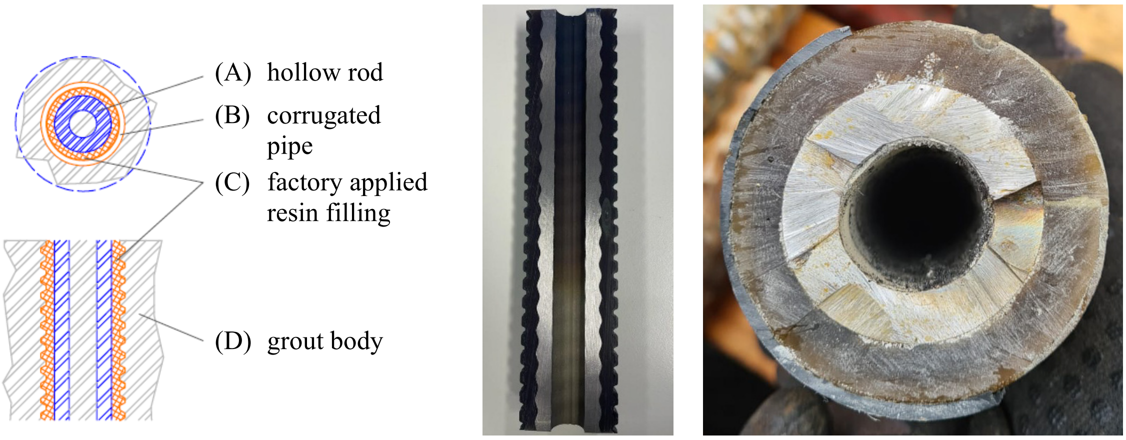

Figure 4. Developed double-corrosion-protected self-drilling tension element DCP-SBZ, left: schematic, center: longitudinal-section of a pre-fabricated prototype, right: cross-section after field testing.

The overall concept is shown in Figure 4 on the left hand side. This shows that a hollow rod is used, which is enclosed by a corrugated pipe with a wall thickness of 1 mm. The resulting annulus, which is between 4 and 7 mm depending on the rod diameter, is sealed (factory-made) with a resin. For this purpose, a two-component synthetic resin is used, which has high compressive and tensile strength as well as sufficient abrasiveness.

The first results of this development have shown that a uniform and full-surface coating of the metallic tensile element (see Figure 4 center) can be achieved during manufacturing, providing a continuous corrosion protection barrier. In a series of field tests (DAT, 2022), investigations were carried out to determine whether the applied resin layer can withstand the installation process of rotary percussive drilling. This showed, as can be seen in Figure 4 right, that over a large part of the pile length both the resin body and the corrugated pipe were still intact.

Only in the head area near the drilling bit and in the area of fittings and joints small damages were observed when test bodies in (gravely and sandy) soil were exposed. These damages can be attributed to entrapment and galling of coarse-grained fractions.

2.3 Possibilities and benefits

The concept in section 2.2 shows the development and initial testing of a new type of micropile, which has considerable advantages due to the resin-based corrosion protection barrier and the simple self-drilling installation process. These range from the low installation effort to ensuring the required durability due to the double corrosion protection.

The disadvantages at present are the high costs - due to the expensive resin that has to be used - and the fact that the application of the corrosion protection layer results in a significant increase in weight, which limits the handling by the site personnel. However, the problems mentioned in the area of the drill bit and the fittings have already been solved by further development.

Furthermore, the concept of this micropile additionally offers the possibility of post grouting (due to the core of the hollow rod), which can lead to an increase in the load bearing capacity and subsequently to a reduction in the required pile lengths. In addition to cost savings, this can result in a reduction in installation time, which can be a clear advantage given the difficult installation conditions for protective structures, as mentioned above.

3 TESTING OF MICROPILES FOR PROTECTIVE STRUCTURES

In addition to the development of a new type of micropile, an improvement in the field of testing is also necessary when it comes to protective structures. On the one hand, this is related with the difficult and adverse conditions of the test and, on the other hand, it is also related to the requirement of ensuring a sufficient load-bearing capacity of the tension elements.

Figure 5 left shows a typical set-up for a static (tensile) load test. As it can be seen, the steep terrain, the missing abutments and the limited accessibility require a massive setup. One possibility to reduce the micropile test setup could be achieved, as schematically shown in Figure 5 centre, by reducing the load application (bond) length of the tested pile. The length L_{fixed}, can be considered similar to the fixed length of a pre-stressed anchor, whereas the length L_{app} serves as the apparent free length according to ÖNORM EN 1537 (2015). Therefore, the required test loads could be reduced and furthermore, the inhomogeneity of the subsoil can be addressed using such a setup.

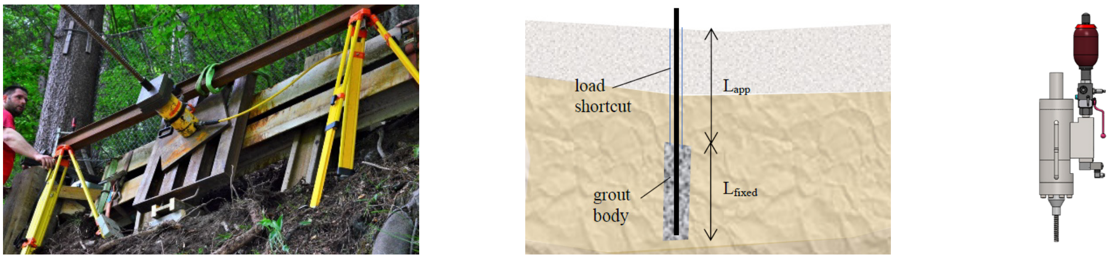

Figure 5. Testing of micropiles used for the foundation of protective structures, left: static load testing, center: schematic for the design of test piles, right: equipment for the dynamic testing of micropiles.

Currently, the creep rate is used as an acceptance criterion for static load tests. However, this is to be considered as a limit value for a long-term load, whereas the main impact on protective structures and especially on rockfall barriers is usually a short-term, impact-like load. One method to bridge the mentioned inaccessibility could be the application of dynamic test methods. However, the current state-of-the-art only allows this method to be used for micropiles subjected to compressive loads. The picture on the right in Figure 5 shows a concept (Haberey, 2023) of a dynamic test device, with which it is possible to apply impulse-like tensile loads to a micropile that reach the load levels of a rockfall event.

4 CONCLUSIONS AND OUTLOOK

This paper gave a brief insight into current developments in the field of the foundation of protective structures through the use of micropiles. Two topics were discussed in this context.

On the one hand, a new micropile type was presented, which is based on the application of a corrosion protection barrier to self-drilling tension elements. The required corrosion protection can be ensured by a resin coating, which is applied to the tension element in the factory. This layer offers sufficient strength and abrasiveness to allow rotary percussive installation even in coarse-grained subsoils. An initial validation in a series of tests demonstrated the effectiveness of this system. Currently, the micropile is further developed, which should enable a subsequent post-grouting and thus an increase of the load-bearing capacity.

On the other hand, the testing of micropiles subjected to tensile loads was briefly discussed. In this regard, the current state of the art shows that an immense effort is required to perform such tests. Current developments in tension testing, but also in the development of rules and regulations, create scope for establishing new testing methods and anchoring them in practice.

This article shows that there is a comprehensive potential for optimisation and improvement in the field of protective structures. Such developments are necessary to ensure the requirements for durability and thus a sustainable operation of the infrastructure, while still guaranteeing sufficient safety of the structures. Taking into account the increase in climate change-related effects, it can be assumed that there will be an increased need for such constructions in the future.

ACKNOWLEDGEMENTS

The developments presented were carried out in the research project DAT - Durability in Anchor Technology (# 873149) funded by the Austrian Research Promotion Agency (FFG). In addition, field tests were carried out during a project financed by the Austrian Railways Infrastructure AG (ÖBB).

REFERENCES

Bergmeister, K. 2009. *Schutzbauwerke gegen Wildbachgefahren. Grundlagen, Entwurf und Bemessung, Beispiele*. Ernst & Sohn: Berlin.

DAT. 2022. *Endbericht Forschungsprojekt DAT - Dauerhaftigkeit in der Ankertechnik*. Technische Universität Graz. Institut für Bodenmechanik, Grundbau und Numerische Geotechnik. Graz.

DIN EN ISO 527-1. 2019. *Kunststoffe – Bestimmung der Zugeigenschaften – Teil 1: Allgemeine Grundsätze*. Deutsches Institut für Normung. Berlin.

Dold, C. 2021. *Versuchstechnische und analytische Untersuchung zum Rissverhalten und Rissbild von Verpresskörpern bei Zugelementen*. Masterarbeit. Technische Universität Graz. Institut für Bodenmechanik, Grundbau und Numerische Geotechnik. Graz.

ETAG 027. 2013. *Guideline for European technical approval of failing rock protection kits*. European Organisation for Technical Approvals. Brussels.

Haberey, C. 2023. *Test methods for micropiles as foundation for protective structures – methods and abort criteria*. Masterarbeit. Technische Universität Graz. Institut für Bodenmechanik, Grundbau und Numerische Geotechnik. Graz.

Mölk, M. & Hofmann, R. 2018. *Schutzbauwerke gegen Steinschlag nach ONR 24810*, In. Berichte der Geologischen Bundesanstalt (125). P. 66 – 89.

Nürnberger, U. 1995. *Korrosion und Korrosionsschutz im Bauwesen - Band 1: Grundlagen, Betonbau*. Bauverlag. ISBN: 376 – 2531994.

ONR 24810. 2017. *Technischer Steinschlagschutz - Begriffe, Einwirkungen, Bemessung und konstruktive Durchbildung, Überwachung und Instandhaltung*. ASI. Vienna.

ÖNORM B 1997-1-1. 2021. *Eurocode 7: Entwurf, Berechnung und Bemessung in der Geotechnik - Teil 1: Allgemeine Regeln - Nationale Festlegungen zu ÖNORM EN 1997-1 und nationale Ergänzungen*, Austrian Standards International, Vienna.

ÖNORM B 4456. 2021. *Geotechnik - Dauerhaftigkeit von Verankerungen*. ASI. Vienna.

ÖNORM EN 1537. 2015. *Execution of geotechnical works – Ground anchors*. ASI. Vienna.

ÖNORM EN 14199. 2015. *Execution of geotechnical works – Micropiles*. ASI. Vienna.