New test method for micropiles subjected to tensile loads – first field tests and validation

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Abstract

Besides being used as conventional foundation element for buildings, a main field for the application of micropiles is the foundation of protective structures, allowing for the transfer of tensile loads into the subsoil. Especially in rockfall protection, micropiles are used to transfer the cable loads into the subsoil. To ensure their functionality, investigation, suitability and acceptance tests are performed to determine the load-bearing capacity. Currently, such tests are performed using a static hollow piston cylinder for load application, and the acceptance criterion is defined by the creep rate. However, such tests are associated with considerable effort, and different boundary conditions in steep areas can influence the test results. Furthermore, the creep rate as acceptance criterion does not refer to the dynamic load-bearing capacity of micropiles used for protective structures. Therefore, a dynamic test method has been developed in which an impulse is applied to the micropile simulating the dynamic loading characteristic. The test set-up is based on the Charpy pendulum impact test and represents a method to simulate an impact-like load, comparable to real load situations of micropiles used for protective structures. First field tests have shown that it is possible to apply such loads on micropiles to simulate in-situ conditions during a rockfall event. However, further research is necessary to extend and improve this test method.

Keywords: Micropiles, Field testing, Dynamic testing, Validation, Test equipment

1. Introduction

Micropiles (EN 14199 2016) are a universally applicable solution for the foundation of structures and for transferring loads into the subsoil. Additionally, to their wide range of appearance and design, these geotechnical elements offer a wide variety of installation methods. In addition to the utilization as a foundation element for structures, where compressive or tensile forces are transferred into the subsoil by vertically installed micropiles, they are also used for protective structures against natural hazards. The two examples in Figure 1 show two of the most common fields of application in this area. Micropiles with or without netting for rock slope protection (Figure 1 a) can be used to stabilise rock sections in road and railway constructions. Micropiles are also often used for the foundation of rockfall protection nets (Figure 1 b), where micropiles are used to transfer the cable forces, and the load of the support structure into the ground.

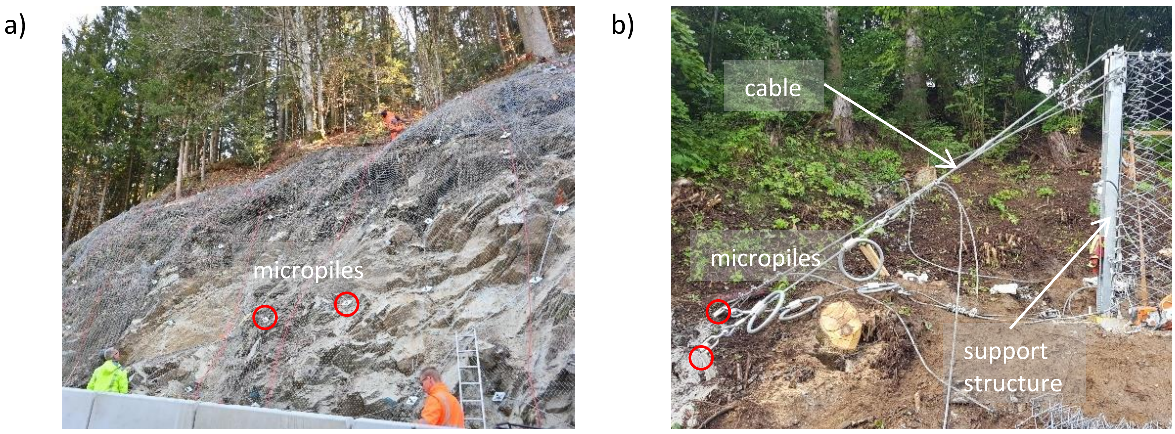

Figure 1: Areas of application of micropiles in hazard protection, rock slope stabilisation (a), cable suspension for rockfall protection structures (b).

In contrast to the application as foundation elements in residential and industrial areas, aspects such as the accessibility of the terrain (see. Figure 2 a), the lack of a sufficient working level and the installation in debris material or in loose to compact rock play a significant role on the quality of micropiles used for the foundation of natural hazard protection structures. Consequently, testing and quality assurance are essential to ensure reliable elements for the load transfer into the subsoil and therefore, the functionality and durability of the natural hazard protection structure itself.

a)

b)

Figure 2: Micropile installation under challenging conditions, hand drill carriage (a), hydraulic drill carriage attached to an excavator (b).

To meet these requirements, different types and designs of micropiles as well as drilling and installation methods, which can be adapted to the requirements of the terrain, the environment and the subsoil are available. Due to subsoil conditions and site accessibility, the installation of driven or pressed micropiles is usually not possible to be used as a foundation for hazard protection structures. Therefore, mostly drilled micropiles are used, which can be distinguished between self-drilling micropiles (hollow bar with lost bit) and cased drilled micropiles. Depending on the corrosion protection, an additional distinction between single and double corrosion-protected elements (ÖNORM B 4456 20221) can be made.

2. Testing of micropiles

Similar to other tensile elements such as pre-stressed anchors (EN 1537 2015) and soil nails (EN 14490 2010), micropiles (EN 14199 2016) must be tested in order to validate the design assumptions (e.g. skin friction) and to ensure the functionality of the structure. For instance, in Austria, a number of regulations must be complied with, depending on the type and the planned use of the structure. Table 1 provides a brief overview.

Standard		**Investigation test**	**Suitability test**	**Acceptance test**
ÖNORM B 1997-1-1 (2013)	# of piles	only in special cases	min. n = 3; min. 3%	not defined
	criterion	tested until failure	$k_s \leq$ 2mm	not defined
ÖNORM EN 14199 (2016)	# of piles	n ≥ 2	not defined	n ≥ 2 each 50 micropiles + min. 1 every 50 additional micropiles
	criterion	tested until failure	not defined	not defined
ÖNORM ONR 24810 (2020)	# of piles	not defined	not defined	n ≥ 1 each 25 micropiles min. n ≥ 2 each row
	criterion	not defined	$k_s \leq$ 5mm	$k_s \leq$ 5mm 1) & 2)
1) load must be held for a time period of 5 minutes				
2) drop in load to be determined				

Table 1: Summary of regulations for the testing of tensile loaded micropiles (acc. to Kainz 2021).

On the one hand, a distinction between investigation, suitability and acceptance test can be made, characterised by their timely occurrence in the course of a project or the necessary information gained from them. Investigation tests are usually carried out when new micropile-systems are used or when there is insufficient knowledge about the subsoil in terms of load-bearing capacity. On the other hand, suitability tests are used to validate the design assumptions in case the bearing capacity has been chosen based on experience and table values (see EN 14199 2016 & ONR 24810 2020). Additionally, micropiles for protective structures are tested after installation using an acceptance test to validate their function.

As one can see in Table 1, there are major differences between the normative principles to be applied to micropiles for protective structures with regard to the testing of these elements. Eurocode 7 (2013) only provides general rules, differentiates between compressive and tensile loads to a limited extent, but does not provide any information on the acceptance test. Similarly, EN 14199 (2016) only provides limited information on the performance of the tests, as this code can be applied to all types of micropiles and does not focus on micropiles subjected to tensile loads used for the foundation of protective structures. In contrast, ONR 24810 (2020) provides comprehensive information on the performance of micropile tests focusing on hazard protection structures as it defines the number of micropiles to be tested as well as the abort and acceptance criteria to be applied. Especially with regard to the acceptance test, extensive statements are made, and requirements are defined. The number of micropiles to be tested is defined as follows: One in every 25 micropiles has to be tested but at least two micropiles are to be tested in each shoring of a rockfall protection structure. The failure of a micropile is defined by exceeding the creep rate k_s according to formula (1), which defines "*the inclination of the time-deformation-line in a logarithmic scale*" (EN 22477-5 2019).

$$k_s = {}^{s_2 - s_1}\!/_{\log(t_2/t_1)} \qquad (1)$$

For micropiles, the creep rate determined during testing is defined with a limit value of $k_s \leq 5$ mm. On the other hand, due to the difficulty of determining the creep rate (see section 2.1), further acceptance criteria are defined in the form of a constant loading over a period of 5 minutes or a maximum decrease of the load of max. 10%.

2.1 Static testing of micropiles

The above-mentioned number of micropiles to be tested as well as the defined abort or acceptance criteria are based on the performance of static micropile tests. These are carried out similarly to these on pre-stressed anchors (EN 1537 2015) by a gradual application of a load and the measurement of the displacements at the head of the micropile (test method 1 acc. to EN 22477-5 2019). A schematic instrumentation of such a test set-up is given in Figure 3 a.

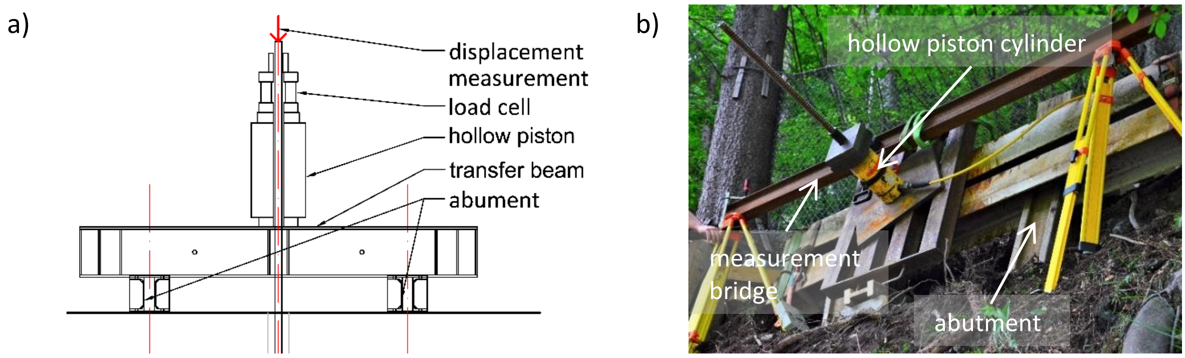

Figure 3: Static testing of micropiles, schematic illustration (a), field testing of micro piles (b).

As one can see in the schematic illustration, the test set-up consists of a hollow piston cylinder, a load transfer beam and an abutment on each side of the load transfer beam, which is necessary to prevent a force locking between the tensile element and the subsoil during load application. This test set-up can easily be used for testing vertically installed micropiles on (almost) horizontal ground. However, when used to test micropiles for rock fall protection structures as shown in Figure 3 b), considerable difficulties become apparent. Besides problems with the placement of the abutments (e.g. removal of non-competent cover layers, compensation of terrain unevenness), the recording of the creep rate at the micropile head is only possible with a lot of effort. Due to the unevenness and steepness of the testing area, the use of a standard stand is not possible, and therefore, other constructions have to be made. One example is shown in Figure 3 b) by installing a measuring bridge to place a displacement sensor on the head of the micropile. In addition to the placement, the reading of the measurement equipment is challenging due to accessibility and required accuracy, as this has a major influence on the determined creep rate.

In addition to these shortcomings, which are associated with the installed and used test set-up, the approach of the creep rate as an acceptance criterion for micropiles used for rockfall protection structures can also be questioned, as the (real) loading is defined by a short-term impact. Therefore, it will hardly affect the creep-related load-bearing behaviour (no long-term stress is expected).

Due to the above-mentioned reasons, the possibility of a dynamic testing of micropiles for protective structures was investigated and is presented in the present work. Thereby, the focus was on the possibilities of dynamic testing and on the creation of a basis for an admissible acceptance criterion.

2.2 Dynamic testing of micropiles

In addition to static testing, the relevant normative requirements (see ONR 24810 2020 & ÖNORM EN 14199 2016) also allow for the implementation of dynamic testing. Such methods (e.g. Steurer & Adam, 2012; see Figure 4 a) usually consist of a drop weight that applies the required test load or, based on its impact, a dynamic response (e.g. Allnamics) of the pile is recorded, and the load-bearing capacity can be derived. In general, as described in chapter 2.1, testing of micropiles subjected to tensile loading is only possible by applying a static test load due to the fact that dynamic testing can only be applied on large diameter piles. For example, methods based on wave propagation (e.g. ASTM 2016) can only be used for large bored piles and usually only provide information about the quality of production and the pile integrity and offer no or only limited information on the bearing capacity.

In order to investigate the method of dynamic testing of micropiles subjected to tensile loads, a test set-up was developed which can apply high dynamic tensile loads on a micropile. For this purpose, the concept of the Charpy pendulum impact test acc. to ISO 148-1 (2016) was adapted. The developed test set-up is shown in Figure 4 b). This shows a schematic representation in which the final position of the test set-up can be seen. In general, a pendulum with a weight of up to 1,200 kg (10 plates with 120 kg each) is used, which is wound up in a starting position (Pos. A) and then performs a guided movement along its axis of rotation. This requires a rigid frame with an almost frictionless mounting of the pendulum in order to reduce friction loss which would lead to a reduction in the applied load. After swinging through the zero position (Pos. B), the pendulum swings upwards and strikes a head plate attached to an extension of the micropile at Pos. C. To allow for this swing-through, the plates of the pendulum are slotted.

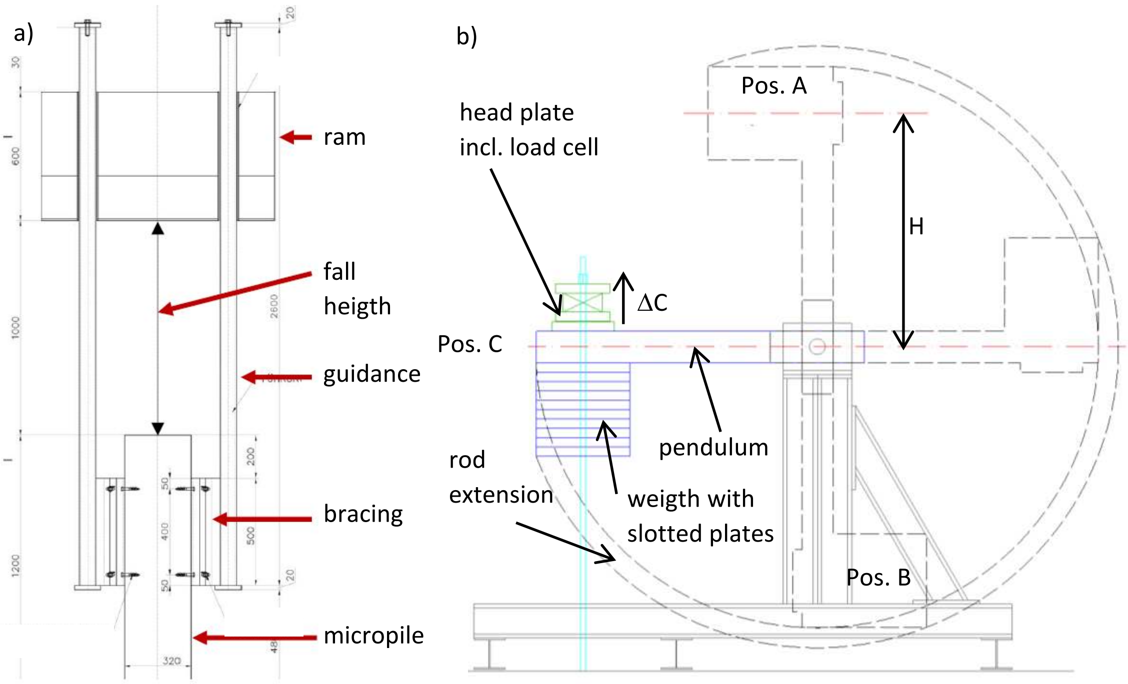

Figure 4: Concept for a dynamic tensile testing equipment for micropiles, dynamic compression testing of micro piles ((a) acc. to Steurer & Adam, 2012), test set-up for field testing (b).

To measure the generated impact (load) on the micropile, a variety of measurement equipment has been installed. In addition to a displacement measurement of the test set-up and the micropile itself, a load cell (see. Figure 5 b) was installed on the rod extension of the micropile. For this purpose, a load cell (hollow ring) was clamped between two steel plates and screwed onto the extension of the micropile using a coupling unit of the micropile. This ensured that the height of the load cell coincides with Pos. C of the pendulum. Furthermore, the parts could be easily assembled and disassembled.

The movements and deformations of the test set-up were recorded using wire ropes, which were attached to an independent measuring base and also by displacement transducers mounted on the test frame itself, which recorded the displacement of the micropile. The results of these investigations (see also DAT 2022) are not described in detail. However, it became apparent that a massive displacement of several centimetres of the entire test set-up took place, which followed the movement of the pendulum.

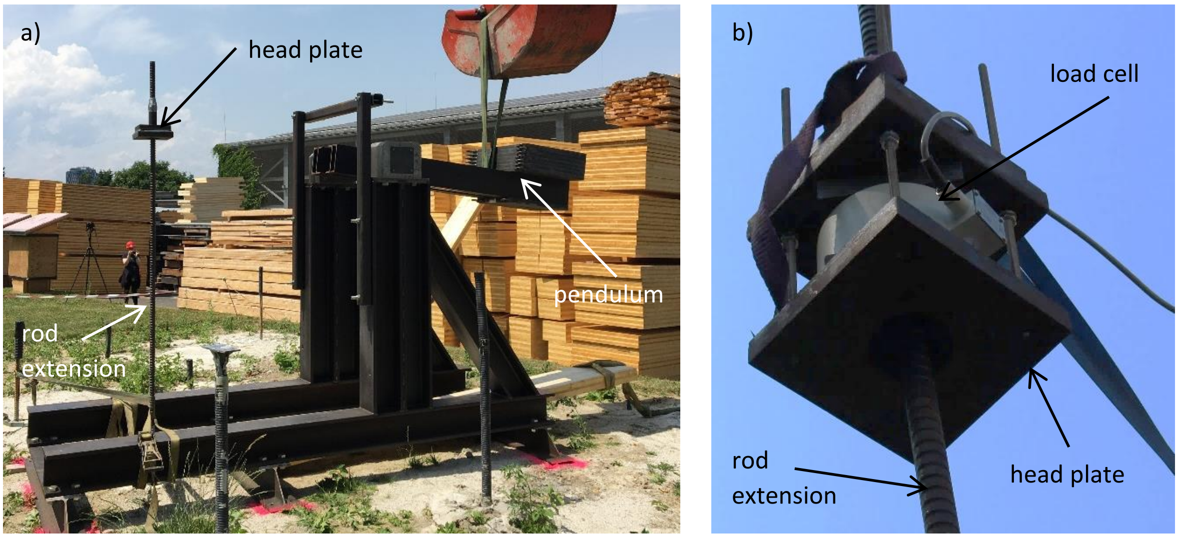

Figure 5: Dynamic tensile testing equipment for micropiles used in field tests; overview (a), detail on load measurement unit at the micropile extension (b)

The field tests were carried out at a test site (DAT 2022), where the installation quality of different types of micropiles was investigated. The installed micropiles for these tests were solid bars, which were installed using a cased drilling and had an embedment length in the subsoil of 4.00 m. The subsoil consisted of a slightly silty, sandy gravel overlain by 2.50 m of backfill. The bar used was a SAS 550 (ANP-Systems 2016) with a diameter of 32 mm, which has a characteristic breaking strength F_{pk} of 400 kN. In the course of the field tests, in addition to static micropile tests, a series of dynamic tests were carried out using the test set-up described in section 2.2. The results of a representative series of tests are given below. Further test results can be found in Kainz (2021) and DAT (2022).

3. Results and interpretation

Overall, six tests on two different micropiles have been performed during the described field tests. For visualisation purposes, only a single representative test result is shown and discussed in the following section.

The left graph of Figure 6 shows a test in which a height difference (H in Figure 4) of approx. 1.6 m and a pendulum weight of 1,080 kg was used. The measured force at the load cell is shown over the test duration. First of all, it can be seen that the overall test period was less than 7 seconds. Additionally, one can observe that a triple swing at about 1.8 sec, 4.3 sec and 7.3 sec is executed by the pendulum during this period, which is due to the low friction of the entire pendulum.

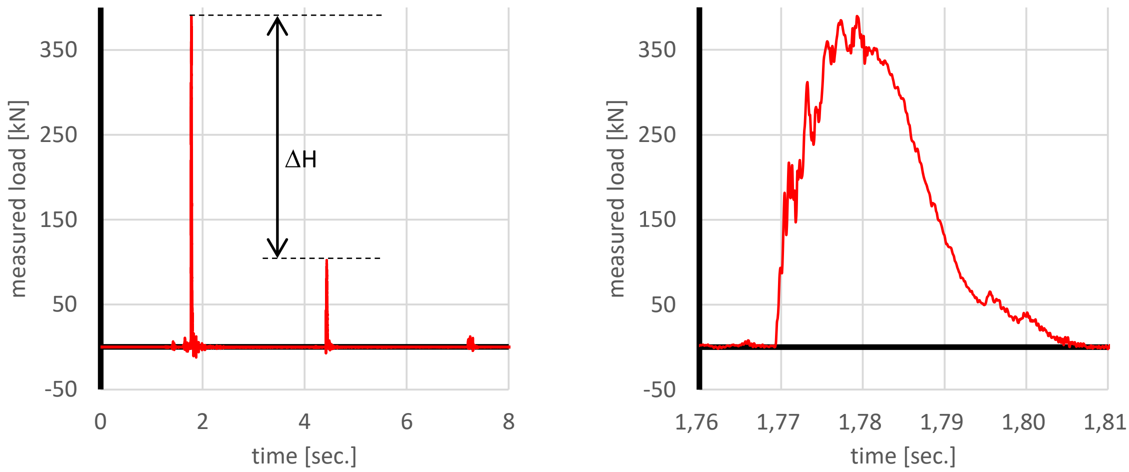

Figure 6: Measurement results of a dynamic test of a tensile loaded micropile

The graph on the right shows a detailed section of the test results, in which only the first swing of the pendulum (from hitting the head plate at ~1.77 sec. to 1.81 sec.) is shown. Here it can be seen that there is a rapid increase in the measured load, which has a magnitude of approx. 365 kN, before a drop in the measured load takes place due to the pendulum swinging back.

This test series has shown that the described test set-up based on the Charpy pendulum impact test can be used to apply dynamic loads. Therefore, based on previous results, possible acceptance criteria for a dynamic micropile test were defined.

First of all, the difference in the measured load between the first and the second swing of the pendulum (ΔH in Figure 6) could indicate the extent where the ultimate skin friction between the micropile and the subsoil was mobilized in the course of the test and consequently, a vertical displacement of the micropile occurred. As a result of such a permanent displacement, a small increase in the height of the head plate (ΔC in Figure 4 b) would occur, which would require a small amount of additional energy to apply the second hit. Secondly, a difference in the load patterns due to multiple executions of a test on the same micropile could indicate a decrease in bearing capacity of the micropile, as this would again result in a vertical displacement of the micropile and, consequently, an increase in the applied potential would also be required. Thirdly, in addition to a purely force-based interpretation of the test results, the recording of the deformations of the micropile also represents a possible basis for an acceptance criterion. In contrast to the already mentioned creep rate. However, the maximum vertical displacement of the micropile head is of interest here.

The three possible acceptance criteria listed above show that there is a range of possibilities for verifying the dynamic testing of micropiles subjected to tensile loads. On the one hand, a force- or displacement-based evaluation can be carried out, but on the other hand, a combination of these measured variables can bring considerable added values. Furthermore, it must be taken into account that this type of test may require an entirely new definition of load transfer between the micropile and the subsoil. Currently, when designing micropiles for long-term loads, it is assumed that failure occurs between the subsoil and the grout body. Thus, the design can be carried out on the basis of skin friction characteristics. In the case of dynamic and sudden loading, this can change due to the prevailing inertias of the system, which would require an adjustment of the acceptance criteria but also of the design concept of the considered micropiles.

4. Equipment development and improvement

In section 3, a new concept for dynamic testing of micropiles subjected to tensile loads was presented, which was implemented in the form of a prototype in the course of field tests. As described, these field tests were carried out on vertically installed micropiles, which were easily accessible. In order to be able to use the presented concept for micropiles of protective structures in rough terrain, a handy and portable dynamic test cylinder for micropiles was developed (Rebhan et al, 2021).

This prototype is based on a pre-tensioned hydraulic cylinder, which enables an adaptation to the required test load by regulating the hydraulic pre-tension. In the future, the applied impulse during testing may be used to draw conclusions regarding the applied load.

5. Conclusion

The results of the investigations presented in this paper show that it is possible to dynamically apply tensile loads on micropiles for testing and validation purposes while achieving practically relevant load levels. This type of test would have advantages in terms of execution time and also in the representation of short-term loads (e.g. impact or rockfall). However, so far, no experience regarding the complex load transfer mechanisms of dynamically loaded micropiles is available. Furthermore, the equipment presented is only applicable to a limited extent on practical conditions (due to its massive construction and the necessary transport and site logistics).

However, the results of the measurements have shown that possible acceptance criteria can be derived on the basis of such an impulsive or impact-like testing method. Furthermore, these tests have shown that it was not possible to determine the limit load-bearing capacity of a micropile, but a binary statement regarding the fulfilment of the load-bearing capacity requirements can be given. In addition, this test method offers the possibility of recording the load-bearing behaviour and the load-dissipation mechanisms for micropiles subjected to short-term loads. Thus, it enables the further development of design methods and the optimisation of the construction of such geotechnical elements.

Furthermore, in the course of ongoing development, a reduction of the test set-up to a portable level has been achieved. This equipment can be used primarily in the area of rockfall protection structures and micropiles in areas that are difficult to access. Together with this equipment development, the applicable measurement technology is also being investigated. The focus is on the recording of the impulse in order to be able to quantify the influence of the subsoil in addition to the applied stress. In addition to acceptance tests, the presented setup can also be used for suitability and examination tests and thus contribute to an optimisation as well as a sustainable and economic execution of micropiles.

Finally, it can be noted that the application of new testing methods in the construction industry and especially in geotechnics is increasing. Besides the developments in the field of digitalisation, this is mainly due to the increased requirements regarding quality assurance and the optimisation of execution solutions, which require increased attention in order to ensure the reliability of constructions.

Acknowledgements

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