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Safety assessment of existing retaining structures

Évaluation de la sécurité des structures de soutènement

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ABSTRACT: Over the last years, an increase of damage and defects on geotechnical structures has been observed during safety assessments. This is related to the rising age of these structures, sometimes a change of utilization and loads and in many it is related to a decrease of the bearing capacity. The handling and dealing with these existing structures will be a challenging task for future civil engineers. The research project „SIBS "(Safety assessment of existing retaining structures) focuses on the development and the investigation of new methods for the damage detection and safety assessment of retaining structures. The focus of this paper is to demonstrate new measurement technics and accompanying numerical investigations to determine the behavior due to the possible increase of a corrosion damage.

RÉSUMÉ: Au cours des dernières années, une augmentation des dommages et des défauts des structures géotechniques a été observée lors d'évaluations détaillées de la sûreté. Ceci est principalement lié à l'âge croissant de ces structures et à la diminution correspondante de la capacité portante. La manipulation et le traitement de ces structures existantes constitueront une tâche ardue pour les futurs ingénieurs civils. Le projet de recherche „SIBS" (évaluation de la sécurité des structures de soutènement) porte sur le développement et la recherche de nouvelles méthodes de détection des dommages et d'évaluation de la sécurité des structures de rétention existantes. L'objectif de cet article est de démontrer de nouvelles techniques de mesure et les investigations numériques correspondantes pour déterminer le comportement et l'augmentation possible d'un dommage par corrosion. De plus, les résultats numériques sont validés à l'aide d'études expérimentales et de tests de charge sur des éprouvettes de murs en porte-à-faux.

Keywords: safety assessment, retaining structures, corrosion, numerical simulation, experimental studies

1 INTRODUCTION

The geographical and geological situation in Austria (in mountain regions in general) leads to a large number of geotechnical structures that are necessary for the mapping of roads and railways. Besides tunnels and rock fall galleries also a quite high number of retaining structures can be found next to infrastructure lines. Steady rising traffic loads and various environmental influences have a negative impact on the serviceability and the durability of these structures.

These facts in combination with the rising age of the structures lead to a fast deterioration of their condition. Safety assessments (RVS 13.03.61, 2014) conducted on retaining structures have shown a significant increase in damage. Despite geotechnical failure mechanisms, in recent years an increase (Opan, 2017) in concrete-related damage (e.g. concrete spalling, cracking) has been observed (Marte et. al., 2014). The interdisciplinary nature of the problem (between structural and geotechnical engineering) and the limited options for investigation (see chapter 2.1) and damage detection are the main problems when dealing with these structures. Some highly stressed regions of retaining structures (especially for cantilever walls) cannot be investigated directly, therefore an engineering judgement to estimate the condition and the safety of the structure is not possible.

Due to these limitations and other constraints such as maintenance or route availability, the safety assessment of retaining structures, based on the results of a condition detection and evaluation is a challenging task for civil engineers.

2 CORROSION DAMAGES

Corrosion describes a chemical process in which metal and steel material oxidises under the presence of oxygen and an electrolyte. The reaction product of this process is colloquial referred to as rust. The process of corrosion can only be stopped by removing one of the reaction partners (e.g. oxygen or the electrolyte) or the passivation of the surface. The presence of salt results in an increasing conductivity of water (as part of the electrolyte) which leads to an enhancement of the ion transport within the electrolyte and therefore to a significant acceleration of the corrosion process. This damage symptom can especially be found next to roads where salt and chloride is used as a de-icing agent for winter maintenance.

Figure 1 (Rebhan et. al., 2017) shows the effects of corrosion on the reinforcement of a retaining structure. It can clearly be seen, that due to the construction joint of the wall (as exemplary shown in Figure 4), a depassivation of the reinforcement took place and the corrosion process was able to start. Additionally, this process has been accelerated by salt and chloride, leading to a significant reduction of the reinforcement and therefore to a deficiency in serviceability and usability of the structure.

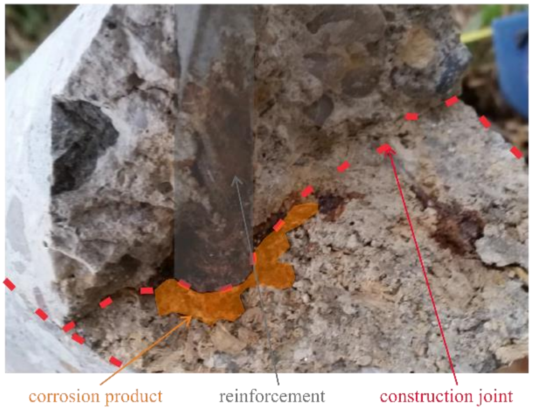

Figure 1: Damage due to corrosion at the construction joint of a cantilever wall

2.1 Investigation methods

During a periodical inspection, the conservation status (RVS 13.03.61, 2014) of a retaining structure has to be determined, depending on the state of the art. For a large number of structures, the condition of the structure (its conservation status) can be determined with sufficient certainty by a visual inspection. Determining the condition and evaluating the damage of a structure is a quite sophisticated and challenging task. Geotechnical deficiencies can often be seen by visual effects such as settlements, tilting of the structure or scarps in the adjacent areas. Structural deficits such as reinforcement corrosion or honey combing on the backside of the wall are nearly impossible to be inspected directly. For an accurate safety assessment, information on possible corrosion defects would be required.

In some areas of civil engineering, non- or minor-destructive methods, are already commonly used. Their application ranges from the detection of material parameters and properties to the identification of areas of risk. These methods can be used to perform minor invasive large-scale and more cost-effective investigations (e.g. rebound hammer, reinforcement detection) to determine missing information on a structure.

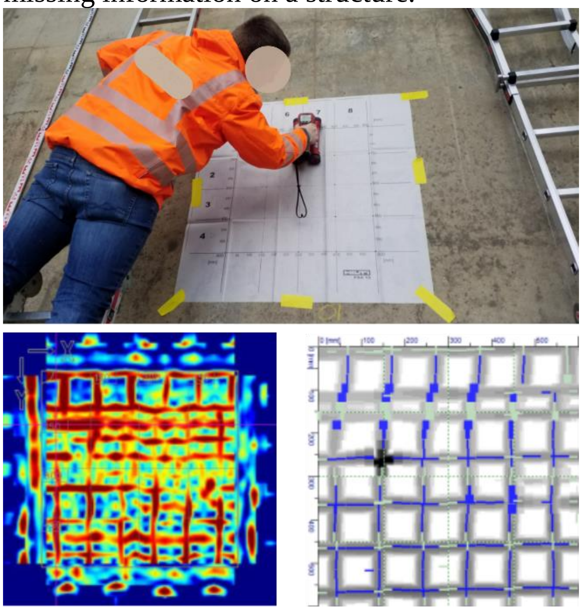

Figure 2: Non-destructive testing methods used for the reinforcement detection of a cantilever wall

Due to the fact that most of these methods are based on wave-propagation, the measurement of the potential or the resistivity between the reinforcement and the concrete the use of non- or minor-destructive methods on retaining structures (as exemplary shown in Figure 2) is often limited to near surface detection. Consequently, these methods are limited by a certain range (max. 40 cm wall thickness). Additionally, the most critical areas to be observed are on the (inaccessible) backside of the wall. Nevertheless, in combination with destructive methods, non- or minor destructive methods can lead to an improvement of the assessment methods and an enhancement of the knowledge about the structure.

Common destructive methods used for the investigation of retaining structures are core drillings (Figure 3 top) and the subsequent installation of an inspection hatch using high-pressure water jetting (Figure 3 bottom).

Given by the fact, that destructive methods are related to lasting changes to the substance of the structure, only a restricted number of these tests can be used on a structure.

Figure 3: Core drilling used to determine the thickness of a wall and to gather a material sample (top), subsequently installed inspection hatch using high-pressure water jetting (bottom)

2.2 Corrosion on cantilever walls

Corrosion of the reinforcement leads to a reduction of the bearing capacity of structures. Quite often the highly loaded regions of cantilever walls overlap with sensitive areas such as the construction joint between the foundation slap and the vertical wall. Figure 4 shows a cross section of a typical cantilever wall, and some examples for these highly stressed and vulnerable regions. The reinforcement in these critical areas of the structure is not only necessary for the durability and serviceability of the structure, it is also essential for the internal bearing capacity. Corrosion in this region of a structure is a common problem, which results from the weak points (construction joints) of this type of retaining structure.

On the one hand, these areas can be inspected using the destructive methods described in chapter

2.1. On the other hand, the methods described, offer limited investigation results, given by the restrictions of the destructive methods such as the diameter of a core drilling or the size of an inspection hatch.

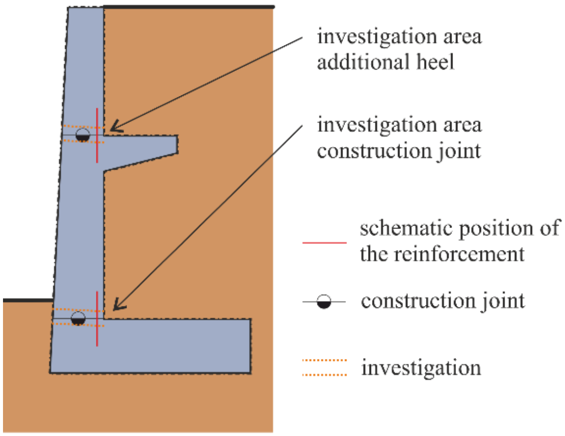

Figure 4: Cross-section of a cantilever wall with additional heel, representation of the possibly performed investigations

Certainty on the results can only be achieved by spreading the investigation area. This is in general only possible by installing a manhole (Figure 5) on the back side of the wall.

Figure 5: Visual inspection of the reinforcement on the backside of a cantilever wall due to the installation of a manhole (Vollenweider, 2014)

This type of inspection method can only be performed on structures which offer the required space for the installation. Additionally, this process leads to high costs and often the necessity of a road blockade or a detour.

2.3 Observation methods and monitoring

To ensure the safety and the usability of roads, railways and other infrastructures an observation (monitoring) of geotechnical structures is performed. The installation of geodetical targets (Figure 6) or the installation of tilt sensors is state of the art for such a monitoring task. This kind of observation allows the detection of rotational and transversal deformations of a structure. But in many cases it is not possible to quantify between different failure mechanisms or deformation sources such as geotechnical failure mechanisms (e.g. tilting or sliding) and corrosion damage.

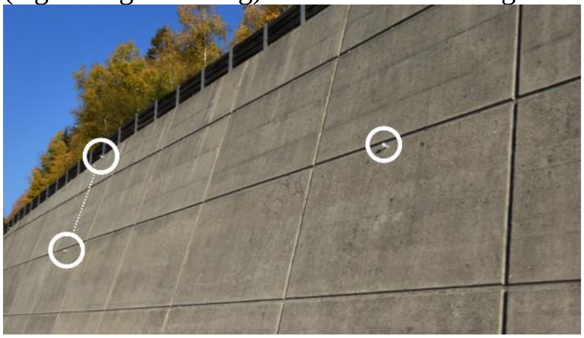

Figure 6: Geodetical targets installed on a retaining structure

Therefore, a new monitoring system for corroded retaining structures (especially cantilever walls) is proposed. This system uses the combination of classic tilt sensors and combines these measurement results with measured concrete strains on the frontside of the wall, whereby it is important to get these data on several levels of the cross section. The combination of data from these two sensor types for different levels of the wall could offer the possibility to distinguish between effects related to load changes, temperatur effects and an increasing corrosion damage of the reinforcement. As one can see in Figure 7, a number of tilt sensors (Δα) and strain sensors

(Δε) is placed along a vertical section of the wall. When measuring wall deformations over time with the combination of the results from the tilt and the strain sensors, a distinction between the different damage sources should be possible.

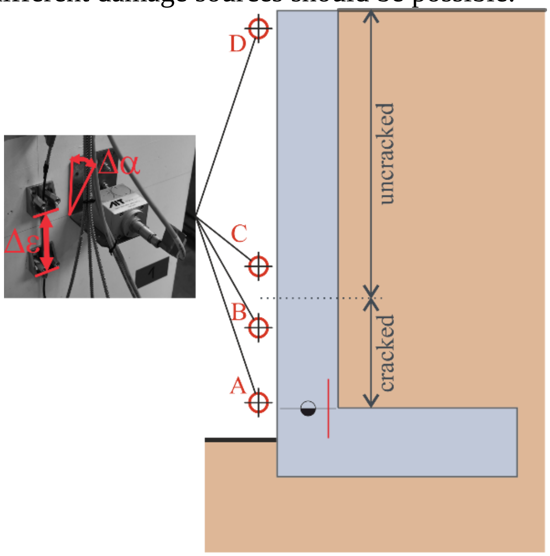

Figure 7: Monitoring system for the observation of corrosion defects on cantilever walls

Table 1 shows the concept behind the different sensor positions and the possible interpretation of the results given by changes in the values for the different sensor positions (Figure 7 A – D) and the two types of sensors (tilt and strain).

Table 1: Significance of the different sensors concerning different effects, actions and possible mechanisms

mechanism	**sensor**							
	tilt				**strain**			
	A	**B**	**C**	**D**	**A**	**B**	**C**	**D**
load changes (e.g. earth pressure)	X	X	X	X	X	X	-	-
temperature effects	-	X	X	X	X	X	X	X
corrosion effects	-	-	-	X	X	X	-	-

Table 1 shows, that for different types of failure, different results of the sensors are given. First of all, a distinction between the sensor type can be seen. While the tilt sensors show an influence on rotational deformation, the strain sensors respond more likley to changes related to the bearing capacity of the structure. Furthermore, the vertical position of the sensors influences the measurement. Essentential is the position of the "point of rotation" also seen as dotted line in Figure 7 between the cracked and uncracked region. With an increasing earth pressure the cracked region is moving upwards, while an increased amount of corrosion should have no effects on the point of rotation.

3 NUMERICAL INVESTIGATIONS

To come up with the measurement concept described in chapter 2.3 a cantilever wall with corrosion damage (Figure 8) has been numerically modelled (Rebhan et. al., 2017) and parameter studies have been performed. Finite Element Analysis were performed to simulate corrosion effects to evaluate the influences on the ductility of the system. Different wall configurations and varying earth pressures acting on the wall have been investigated to determine the possibilities for an identification of corrosion induced damage.

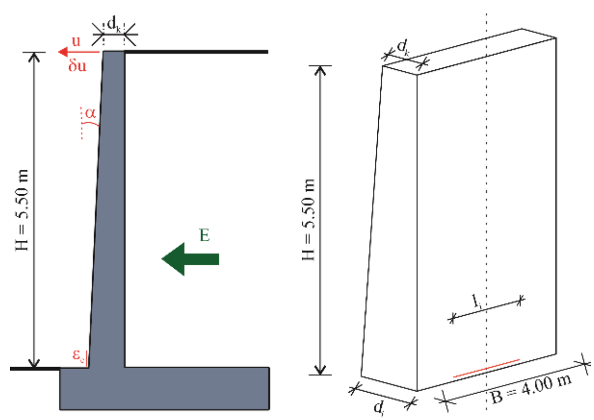

Figure 8: Schematic figure of the investigated cantilever wall (Rebhan et. al.)

These numerical simulations of a reinforcement corrosion on the back side of a cantilever wall have shown, that a classical monitoring of the inclination of the wall solely does not offer the possibility to distinguish between an increase in the load level of the structure, temperature effects or the effects given by an increasing corrosion process. Further advanced nonlinear FEM studies were performed as a basis for the experimental studies on cantilever walls. Figure 9 demonstrates results from these numerical studies, which demonstrate that the inclination of the cantilever wall is more sensitive to the change of loads than to different corrosion stages. Also, the position of the rotation point is moving upwards with an increasing load level, while an increase in corrosion has a minor influence.

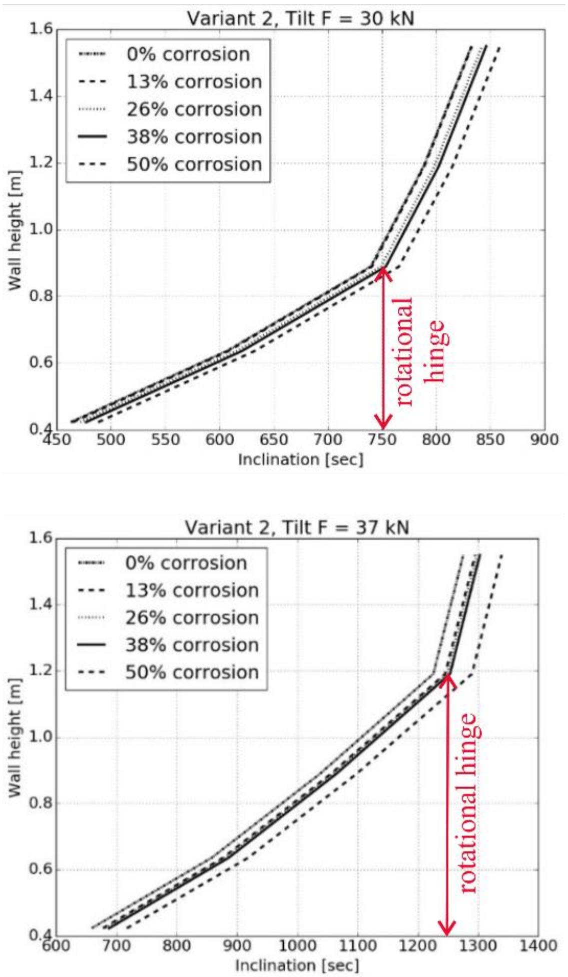

Figure 9: Results of nonlinear FEM- investigation of different corrosion stages under different load levels

Additionally to the numerical simulations of the structural part of the wall, the acting earth pressure on the wall (mobilized as a consequence of the deformations) has been investigated. These studies (Koppelhuber, 2017) have shown, that a significant decrease of earth pressure from an at rest state to the active earth pressure takes place with ongoing deformation. Meaning that a corrosion sourced deformation of a wall could lead to an earth pressure reduction until the level of active earth pressure is reached.

4 EXPERIMENTAL STUDIES

Experimental studies to verify the monitoring system described above and to validate the numerical simulations have been conducted. A picture of the mock-up is shown in Figure 10.

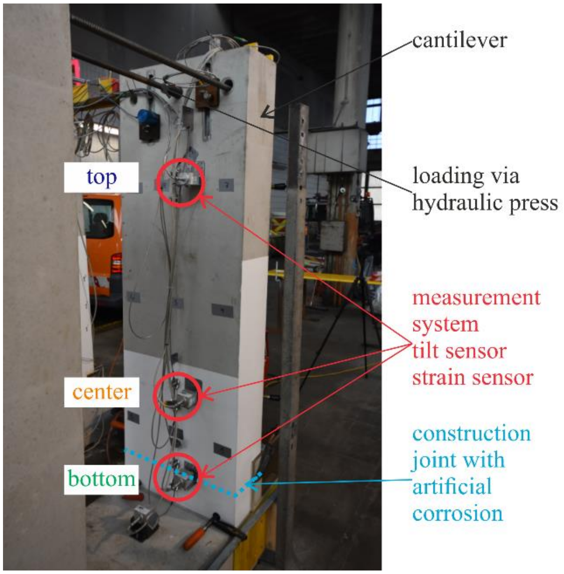

Figure 10: Mock-up for the validation of a monitoring system for corroded cantilever walls

For the validation of the system different cross-sections (degree of reinforcement) and varying corrosion patterns have been tested. The corrosion of the reinforcement has been simulated using Electro Chemical Machining.

The test setup represents the lower third of a 5.50 m high cantilever wall with a thickness of

25 cm. As one can see in Figure 10 the tilt and the strain sensors have been placed along a vertical line on the test body, which represents the front side of a cantilever wall. The sensor positions have been chosen in the uncracked area (top), the cracked region of the structure (center) and the area which is cracked and influenced by an artificial corrosion damage (bottom) of the cantilever. In addition to the sensors shown in Figure 10 further measurement equipment has been installed to verify the system behavior during the test. The cantilever has been loaded by a hydraulic press using a load distribution unit at the top of the wall. This loading point represents 1/3 of the height of the 5.50 m high structure, the rest of the structure has not been modelled in the mock-up.
First results of this tests are illustrated in Figure 11. The x-axis schematically represents the time to conduct the test and to reach a corrosion level of 50 % of the reinforcement area. On the left y-axis the concrete strains on the front side of the wall (compression) are shown. The right y-axis represents the measured changes in the inclination (tilt) of the structure.

The measurement results show:

(1) A sufficient corrosion causes a rotational hinge in the lower wall section.

(2) The changes in tilt show the same trend along the wall height during the increase of corrosion.

(3) The cracked and uncracked areas of the structure can clearly be identified.

(4) Despite the differences in the concrete strains for the different areas of the structure, the influence of the corrosion joint on the strains can be identified.

These first results have shown, that the combination of tilt and strain sensors is a promising approach to determine ongoing corrosion on cantilever walls (as long as the structure itself is still in a ductile state). Furthermore, an identification of load, temperature or damage related effects might be possible, depending on the identification of external influences to the measurement system and the possibility of compensation measures (e.g. temperature compensation).

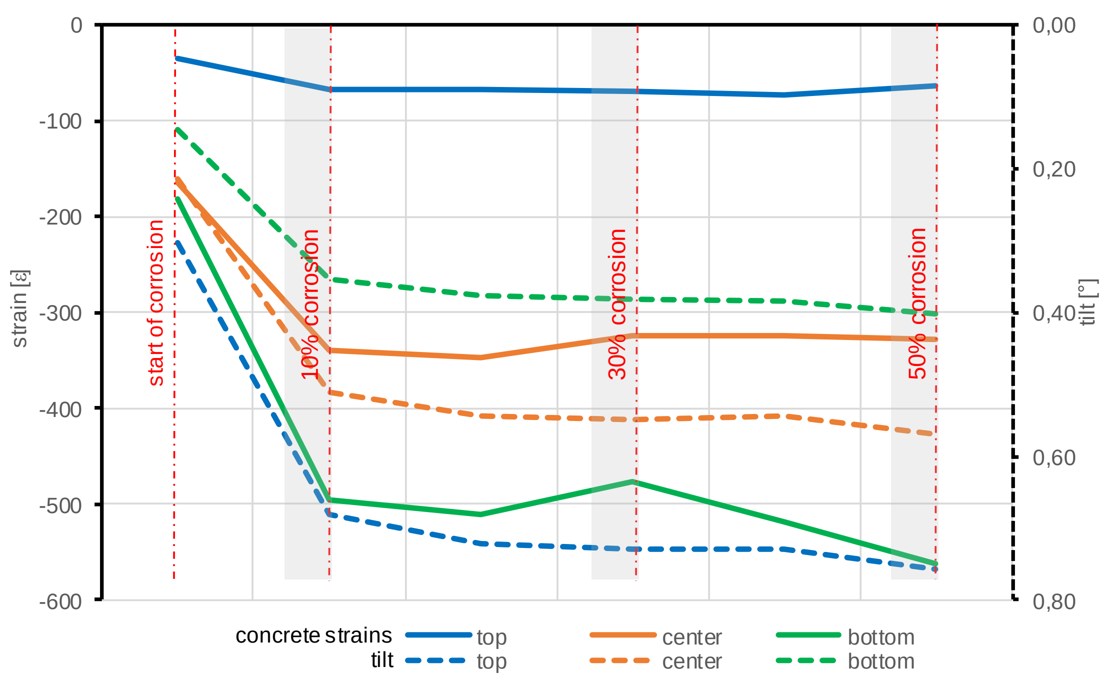

Figure 11: Measurement results of an artificial corrosion damage induced to the test setup

5 CONCLUSIONS

The paper presents investigations for the condition detection and the safety assessment of existing retaining structures. Results of a numerical study to simulate the corrosion damage of a cantilever wall have been described and a new monitoring system for this kind of damage was proposed. Furthermore, first results of experimental studies and nonlinear FEM simulations show the possibilities on the simulation of corrosion on cantilever walls. The results are used to investigate the proposed monitoring system. Ongoing research on this topic, especially the validation of the monitoring system, is under progress.

6 ACKNOWLEDGEMENTS

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