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Special Topic: Focus on responsibility

Corporate culture / ESG
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Micropiles / Durability
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Special Topic
Focus on responsibility

Cover Page

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The reference project shown consists of two identical, single-stage main mine fans with an impeller diameter of 3 m. The motor power has a total of 2 x 1.3 MW at an operating voltage of 6 kV at 50 Hz.

The in-house CFT fan test stand in Marl (NRW), where impeller diameters of up to 4.2 m can be tested in compliance with standards, will be completed in 2023.

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Special Topic

Focus on Responsibility – from inner Conviction

Dr.-Ing. M.A. Katrin Brummermann

Taking responsibility as a result of inner conviction – in both private and professional contexts – helps us cope with today's immense personal and societal challenges.

Editorial • Responsibility • Future • Activity • Conviction

Responsibility can weigh us down. It means being responsible for our behaviour, and possibly even having to give honest answers to difficult questions in court. In our professional activities and private lives, we have to comply with many regulations which we may not always fully understand, and we are aware of possible penalties if we violate these. But all this is not the first association which currently comes to mind when I think about responsibility.

Responsibility not just out of Duty but from inner Conviction

We can also take responsibility voluntarily, in a positive sense because of conviction, and not out of fear of penalties which may result. Parents take responsibility for their children out of love. Others look after people who have fallen on hard times. Out of love for nature, people treat it with care. Those who are fascinated by the wonders of the earth want to preserve these for our current and future generations; they want to enjoy these wonders and conserve the earth's resources out of appreciation for nature and mankind. There are many more examples which could be given here.

It is remarkable that people make commitments for affairs of the heart with all the strength and perseverance they possess. Despite the effort this requires, they usually see the commitment as a positive responsibility. They do not first and foremost think about their own material gain, but they are still rewarded – though experiencing satisfaction, for example.

Positive Identification at Work

In our sectors of geotechnics, tunnelling, and mining/raw materials, we also have a wide range of possibilities and opportunities for positive identification with our work; we can decide to make a voluntary contribution to solving the major challenges facing society – resource-conserving infrastructure and lifestyles, environmental and climate protection, better living conditions in poor countries – to name just a few issues. An inner conviction like this contributes significantly to our own well-being, but it also has a contagious effect on others – in our own work team, in the professional world, in politics, in public, among family and friends, when recruiting professionals and successors, etc.

Positive Examples inspire

A willingness to take responsibility is also reflected in this issue of GeoResources Journal – for example, for responsible corporate governance, responsible mining in Africa, resource conservation through recycling and circular economy and the clearing-up of damage to the environment. As well as environmental aspects, social and economic aspects are also included.

Despite the many challenges, no individual is expected to save the whole world alone, but, as the articles show, we can all contribute what we know and can do without feeling overtaxed. I hope you will find inspiration for yourself and your own work when you read this issue, that it may instigate some creative ideas for future responsible action and behaviour – emanating from inner conviction and radiating outwards.

I wish you an interesting read
Katrin Brummermann

GeoResources Editors

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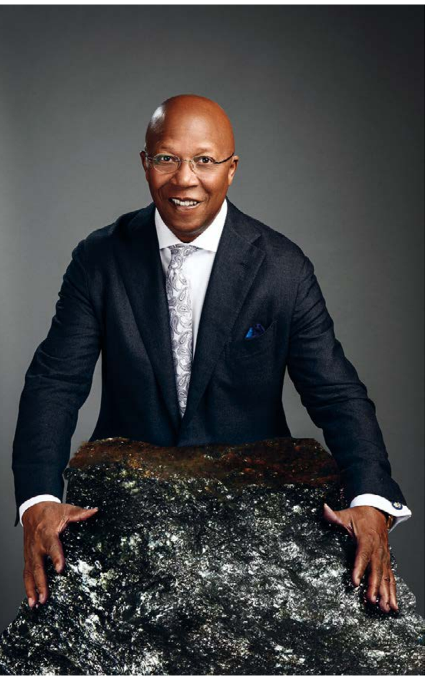
Special Topic

Doing well, doing good

Ambassador Charles Stith and Dr. Mary Mildred Stith, The Pula Group, US-based company with offices in Los Angeles, USA Dar es Salaam, Tanzania and Johannesburg, South Africa

The Pula Group has embraced a dynamic model for corporate citizenship that provides a conceptual framework for crafting a strategy for a company **"to do well, while doing good"**. The model is a guide for corporations to be more responsible citizens in the communities where they do business.

Mining • Responsibility • A Word on • ESG • Corporate culture



When asked to contribute to the issue of **GeoResources Journal** with the special topic "Focus on responsibility" we were honored. We were also impressed that a journal for mining, tunnelling and geotechnics would be taking on such a topic. It is an important signal that a specialist journal is focusing on the need for the industry to give greater importance to the responsibility to be better corporate citizens. The Pula Group has dedicated itself to establishing a new model for mineral exploration operations in sub-Saharan Africa, as such we believe we have something to contribute to this conversation.

The global market place is defined by a number of characteristics – the fluidity of capital, the portability of production, the transferability of labor, and universal media coverage, which exposes every company to a new and heightened level of scrutiny as to where and how they do business. All of these elements have combined to result in a greater level of accountability for businesses, beyond their shareholders and the regulatory bodies to which they report. In this more transparent era in which we live, companies are "accountable" to the public, multilateral organizations, nongovernmental organizations, and media outlets to an unprecedented degree. In emerging markets, the level of scrutiny is even greater. Against the backdrop of colonial exploitation, liberation, and the push for democratization and development in such countries, there is an expectation that the governments of emerging market countries (EMC) will and should be more concerned with economic development and its sustainable impact on the lives of the people of their countries.

The subtext relative to doing business in emerging market countries, is that it is not enough for corporations **to do "well"** by their shareholders, they are also expected **to do "good"** in the markets where they're present. Rather than a problem or imposition, the corporations that understand this as an opportunity will be poised to do business anywhere in the world and they will be welcomed everywhere in the world. Most EMCs now have a baseline of expectations for companies wanting to do business in their countries. Those expectations include a company providing employment opportunities, procurement opportunities, and strategies to mitigate environmental degradation. Good corporate citizenship requires more. The Stith Doctrine is that companies that are prepared **to do well, while doing good** will have a distinct market advantage and as such will be more profitable.

Toward this end, our company has embraced a dynamic model for corporate citizenship that provides a conceptual framework for crafting a strategy for a company **"to do well, while doing good"**. This model reflects insights gleaned over three decades as civic leaders and business innovators and is a guide for corporations to be more responsible citizens in the communities where they do business.

There are six individual elements in the model, which represent distinct factors and are correlative. Each element has implicit questions to be answered:

- **Political Impact**
  Who are the key players, what incentives or disincentives are necessary to precipitate a desired response? The a priori political question is – Is there a way to "**do well and do good**?"
- **Regulatory Impact**
  How does a project (or a company's policies) conflict with, complement, and/or potentially change a regulation or the regulatory environment?

- **Economic Impact**
  How does the project change the development profile of a community or country; and impact on the profitability model for the company?
- **Individual Impact**
  What are the employment (internships, etc.) and procurement opportunities to be derived from the company's presence (or project) in the community? How far upstream and downstream do those benefits flow?
- **Institutional Impact**
  Are community-based (and/or country-based) institutions strengthened? What is the company's institutional legacy? What's left after you're gone?
- **Media Impact**
  What story does the company want to tell and how does it tell this story? The bottom line – what does the media say who the company is as a result of what it has done? Or, what does the media say about what the company has done as a reflection of who it is?

All six elements must be incorporated into an integrated strategy to have maximum country impact. All of these elements are three-dimensional in that they have local, national, and international implications. Clearly, these implications are weighted to varying degrees; but all are factors in this transparent era in which we live. The matrix of questions implicit in each element provides a thorough lens for a company to identify critical variables and enable a company to position itself positively and responsibly in a country in which it does, or wants to do, business. While each element has a common meaning, each has a special meaning and implications in terms of policy formulation and policy action as well.

The sum and substance of this model is that it represents a comprehensive, dynamic, and adaptive approach to addressing the universal issue of a company's responsibilities in an increasingly transparent marketplace. This model promotes accountability as well. Sharing our approach – supported by strategies, tactics, and tools – is intended as an example of the broader shift toward more transparent, responsible, and accountable corporate behavior in the mining industry. We hope this is a helpful contribution to ongoing industry-wide dialogues and efforts to set new standards in an industry that is foundational to human society.

Yours,
Ambassador Charles R. Stith
and Mary Mildred Stith

Ambassador Charles R. Stith

is currently the Executive Chairman of The Pula Group. He served as the Ambassador of the United States to the United Republic of Tanzania in the traumatic period after the 1998 bombing of the United States Embassy in Dar es Salaam. Because of his able leadership, the Embassy emerged from the bombing stable, and set a new standard for U.S. Embassies promoting U.S. trade and investment in Africa. Stith worked with the Tanzanian government to enable them to become the first Sub-Saharan African country to reach the decision point for debt relief under the enhanced Heavily-Indebted Poor Countries Initiative (HIPC).

Ambassador Stith is a member of the Council on Foreign Relations and was on the Advisory Committee of the Office of the U.S. Trade Representative. He is a founder and Non-Executive Chairman of the newly established Johannesburg-based African Presidential Leadership Center. He was the founder and former National President of the Organization for a New Equality (O.N.E.), which focused on expanding economic opportunities for minorities and women. Prior to heading O.N.E., he was the Senior Minister of the historic Union United Methodist Church in Boston. Ambassador Stith was formerly on the Faculty of the Boston University Department of International Relations, where he taught a course on Africa and Globalization and was the founding director of the African Presidential Center at Boston University.

Dr. Mary Mildred "Mimi" Stith

is President of the Pula Group – a family of companies focused on high value investment opportunities in Africa. Under her leadership, the Group has developed an ethical model for mineral exploration and mining in sub-Saharan Africa with a focus on battery minerals. An East Africa specialist and fluent in Swahili, Stith has also worked throughout the continent for more than a decade and a half. At Boston University's African Presidential Center (APC), she led the communication strategy in sixteen African countries. While at APC, she also served as the interim attaché to the former President of Mauritius, His Excellency Karl Auguste Offmann.

She holds an M.A. in Quantitative Methods for the Social Science from Columbia University and a B.A. in Philosophy from Spelman College. Blending quantitative and qualitative methods, she conducted environmental research at Columbia University's Earth Institute and served at the American Museum of Natural History's Center for Biodiversity Conservation. She was a post-doctoral researcher in the AfricanBioServices project at the Norwegian University of Science and Technology. Stith earned her Ph.D. in Anthropology from Boston University. She was awarded a U.S. Fulbright Fellowship for her research on the intersections between resource extraction and conservation in Tanzania.

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Corrosion Protection of Micropiles

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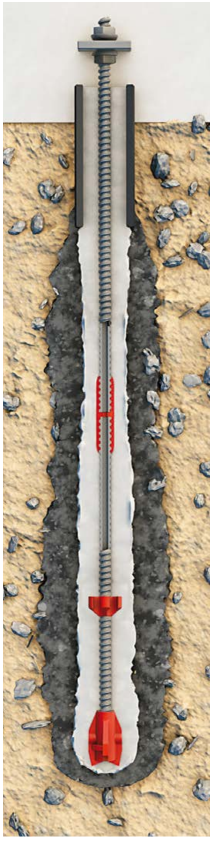

Fig. 1: Cross-section through typical Type E micropile

Micropiles often provide a favourable solution for deep foundation problems especially when significant constraints such as confined construction sites or vibration limitations have been identified. Often the durability of buried steel elements is closely examined in order to determine the rates of corrosion and methods to reduce this while still maintaining the structural integrity. Practices such as sacrificial corrosion loss or plastic sheaths have become the go-to methods of corrosion protection. Other solutions which have been developed, include protection with grout encapsulation. This paper deals with corrosion protection of micropiles and the guidelines provided in codes and standards with a special focus on EU and USA. Different methods are compared.

Geotechnics • Micropiles • Durability • Corrosion protection • Grout encapsulation • Threaded connection • Structural integrity

Introduction

Micropiles are drilled and grouted, reinforced, non-displacement piles which have minimal diameters of less than 300 mm (12 inches) [1] . These slender elements can transfer very high axial loads to the ground but only very minimal lateral loads. Load transfer takes place through skin friction at the interface grout-ground, and end bearing is often neglected in soft soils and weak rock.

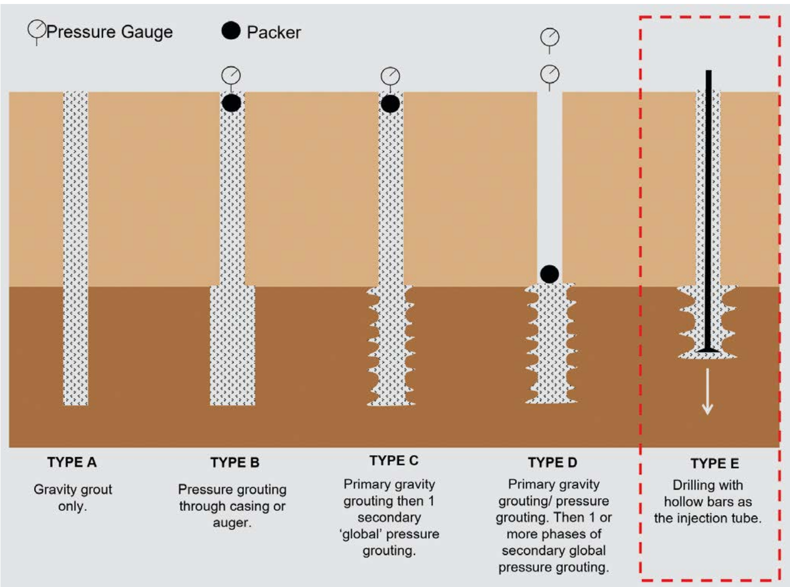

Fig. 2: Micropile classification recognized in the United States [1]

Micropiles are categorized by the method of grout placement and five categories are given in the FHWA's Micropile Design Guideline [1]. In this research, Type E micropiles, highlighted in **Figs. 1 and 2**, were studied. These micropiles are installed using a continuously threaded hollow bar which functions as an injection tube, drilling rod, and reinforcing element.

Of all the micropile variants, the self-drilling hollow bar system has proven to be versatile and often very efficient in urban interventions including locations with significant site constraints. The self-drilling system comprises a hollow threaded bar and sacrificial drill bit. The elements are manufactured in standard lengths – usually 3 and 6 m – and can be extended using coupled connections.

Corrosion protection of steel elements often plays a distinctive role in the initial engineering and design considerations. The durability of a certain element often influences the use of the element to perform the assigned task. Countless articles have been written and research done on exposed structures within the codes but not much effort has been expended on highlighting specific corrosion protection measures for buried steel elements.

In the past, many design engineers have simply adopted the concept for corrosion protection of exposed elements and applied this to buried elements. In sheet piling, the metal is in direct contact with the elements such as air and water which encourage the development of oxides. Extensive research has been done to estimate the corrosion rate of these metals and the effect of atmospheric conditions such as humidity, rainfall, pollution, salts etc. on the corrosion rate [2].

In the ground however, the behaviour of steel is quite different. In addition to the elements being difficult to observe because they are buried, the wide range of soil types makes it extremely difficult to predict the corrosion of metals in every soil type. Furthermore, when the elements are encapsulated in an adequate and effective grout body, as is the case in some micropile installations, only limited research has been done. An adequate grout body can provide a further corrosion protection barrier to the steel and is often overlooked. This is a well known "corrosion protection" method used in sheet piling and very often adopted for micropiles.

The AASHTO [3] and FHWA [1] have outlined different types of micropiles based on the method of grout placement. The different corrosion protection methods in the code are presented and analysed in terms of the appropriateness and useability in practice.

Table 1: Guidance for minimum grout cover for load bearing elements according to Table B1 of EN 14199 [5]

Exposure Class[a]	Chemical aggressiveness	Bearing element with grout cover [mm]		Bearing element with mortar [mm]	
		Compression	Tension	Compression	Tension
X0	with permanent casing	10	10	25	25
X0, XC1 – XC4	not existing	20[b]	20[b]	35	40
XD1, XD2	chloride except salt water	20	20	35	40
XS1	chloride from salt water	20	20	35	40

[a] For other exposure classes in EN 206 minimum cover is given in EN 1992-1-1:2004, Clause 4, and the valid National Annex
[b] For service life of maximum 5 years minimum grout cover may be reduced to 10 mm.

The Codes and Standards

In Europe EN 1997-1 [4], governs geotechnical designs and for each application an execution standard is produced. For micropiles EN 14199 [5] applies specifically to the execution of micropiles [6]. Each country, however, has its own standards that may form part of the common practice. In the United States, the AASHTO [3] and FHWA [1] design guides are often used in the design and implementation of micropiles. These will be further used to argue the case of durability later in this paper.

Corrosion Process

Corrosion is a natural process in which refined metal is transformed into a chemically stable oxide. For embedded steel the corrosion occurs through an electrochemical process whereby the metal is transformed into free ions and electrons due to the interaction with an electrolyte, which in this case is the soil. The process involves both anodic – ions pass from the metal to the solution as free hydrated ions – and cathodic – metals separate from the solution and recombine with the metal – reactions [7].

Specific soil characteristics can present an environment which is conducive to corrosion and it is thus imperative to evaluate the physical and chemical properties in the design phase. In the case of the physical parameters, these can allow the egress of the elements, increasing the corrosion potential of the steel element. Soils such as clays have a generally higher plasticity and are very impermeable when saturated but upon drying the particles shrink. Cracks form and provide the perfect environment for moisture and oxygen to make its way toward the buried element [8].

Resistivity refers to the concentration of ions from dissolved salts and minerals that flow through the soil electrolyte and is an indicator of the soil's aggressivity and contribution to corrosion [9]. Resistivity is a function of moisture content and concentration of ionic soluble salt. As it decreases, for example due to an increase in the sodium content in the groundwater, the corrosion potential increases [10].

The concentration of chemical elements and salts such as sodium, potassium, calcium and magnesium, carbonates, bi-carbonates, sulphates, and nitrates also influences the corrosion potential [8] and must be carefully considered during the design.

In the Eurocodes, exposure classes have been defined to classify the soil types or the environment into different levels of aggressiveness, and the minimum grout cover required is given in **Table 1**. These exposure classes are further explained in EN 1992-1 based on EN 206, which details the following:

- **X0:** no risk of corrosion or attack
- **XC1 to XC4:** corrosion induced by carbonation
- **XD1 to XD3:** corrosion induced by chlorides (not sea water)
- **XS1:** corrosion induced by chlorides from sea water

The FHWA offers guidelines for the evaluation of the soil's corrosion potential. The ground is considered to be aggressive or to have a strong corrosion potential if any of the following conditions, given in **Table 2**, are met. The standard goes on to explain that the possibility of a change in the aggressivity throughout the service life should also be considered.

Corrosion Protection

The codes and standards provide very broad corrosion protection methods but in reality the applicability of these methods has not been thoroughly analysed specifically for Type E micropiles. The methods for corrosion protection include protective coatings, concrete encasement, cathodic protection, plastic sleeves and sacrificial steel.

Table 2: Criteria for assessing ground corrosion potential according to Table 5-5 in [1]

Test	Units	Strong corrosion potential / aggressive	AASHTO test method
pH	-	< 5, > 10	T289
Resistivity	ohm-cm	< 3,000	T288
Sulfates	ppm[(1)]	> 200	T290
Chlorides	ppm	> 100	T291

Note [(1)]: ppm = parts per million

AASHTO also mentions the technique of adopting a larger steel section such that the structural requirements are met even after corrosion [3]. This particular technique works well for steel piles and other elements such as sheet piles, but its relevance to elements with coupled connections – often grouped with other steel piles – is frequently overlooked. The FHWA Micropile Guideline [1] does not list this method of sacrificial steel as a corrosion protection for micropiles but it is only applicable to an additional steel casing, if one is considered. The corrosion protection can be provided through physical or chemical protection or a combination of both [1]. Minimum grout cover should be 1 inch in soil and 0.5 inch in rock, but if galvanization is used, a minimum grout cover of 0.25 inches is acceptable.

In Europe the micropile execution standard EN 14199 [5] also provides similar guidelines stating that the corrosion protection should consider the environmental conditions, the type of micropile, the steel, and the required working life. The corrosion protection may consist of sacrificial thickness, grout, mortar or concrete encapsulation, and specific precautions such as surface coatings.

The type of connection used is very important when considering the different corrosion protection options applicable to steel elements. The way corrosion develops, thickening of the section and allowing the bar to corrode uncontrollably, is rather allowable corrosion and not an effective corrosion protection method. Allowing the bar to corrode can eventually result in corrosion of the threads within the coupled connection during the design life of the project. Once the coupled connection is lost, the bar can no longer fulfill its designed function and must be completely replaced.

Sacrificial Corrosion Loss

The industry has fallen into accepting only the technique of section thickening in order to provide protection against corrosion. In effect, this concept allows the section to corrode to the extent that the element that remains still fulfils the structural requirement of the design. This concept is particularly effective in sheet piles and buried structures like underground pipelines, however its practicality in a micropile system with a coupled connection is yet to be explored and argued.

Although widely accepted, the practice has not been thoroughly investigated to determine its feasibility. Situations have been encountered where the thickening of the section and allowing the steel to corrode uncontrollably have resulted in the failure of elements.

The main concern is the connection. These elements transfer forces and are extended in length using coupled connections. Once the grout cracks and corrosion begins, there is no way to ensure that corrosion does not occur within the coupler. If the threads become corroded, the strength of the coupled connection is lost, and so too is the structural capacity of the element. Effectively allowing the bar to corrode is not corrosion protection but uncontrollable corrosion allowance.

Grout Encapsulation of Type E Micropiles

Grout encapsulation is a simple method that is often rejected by the industry designers who have only designed steel elements using sacrificial corrosion. The concept however is not new, but rather an adaptation of the corrosion protection used in reinforced concrete structures, and these are designed with limits on their cracking which ensure the durability of the reinforcement within.

According to EN1992-1 [11], as part of the serviceability limit state the crack width of the reinforced elements must be verified and the cracking must be limited. This ensures that the durability and strength of the element is not compromised. In reinforced concrete, an adequate concrete cover is required to reduce cracking and essentially this same concept can be applied to a micropile.

This method can be seen as a single layer of corrosion protection. It can also be combined with galvanizing to provide double corrosion protection in cases of highly aggressive soils.

In describing the practices for concrete structures, AASHTO states that reinforcement detailing is important to control the crack width. Furthermore, many small cracks are more favourable than few very wide cracks.

Considering the two most common hollow bar sections available – Rope thread and Titan thread – the cracking patterns can be directly analysed based on the thread patterns present. Under axial loads, the grout is expected to crack, and the magnitude of cracking is directly proportional to the thread pattern. Once the crack width can be limited to less than 0.1 mm, the alkalinity of the grout ensures the protection of the steel member and in some cases these small cracks are even considered self-healing.

Fig. 3 presents the different cracking patterns subjected to axial forces in tension. Based on the thread patterns alone, the rope threads have a much greater splitting force which creates more frequent and larger cracks that extend to the outer edge of the grouted body.

The shape and extent of the cracking pattern along the Titan threads have been extensively studied and it has been confirmed that the cracking pattern is much like that observed in reinforced concrete elements, as shown in **Fig. 4**. According to Issue 525 of the German Committee for Reinforced Concrete [13], the crack widths at the edge of the grout body can be assumed as significantly larger than those at the hollow bar due to warping of the cracks.

One such test featured the installation of some micropiles and then subsequent exhuming of the grouted micropiles once the grout reached its maximum strength. Tensile tests were then performed where the elements were incrementally loaded under laboratory

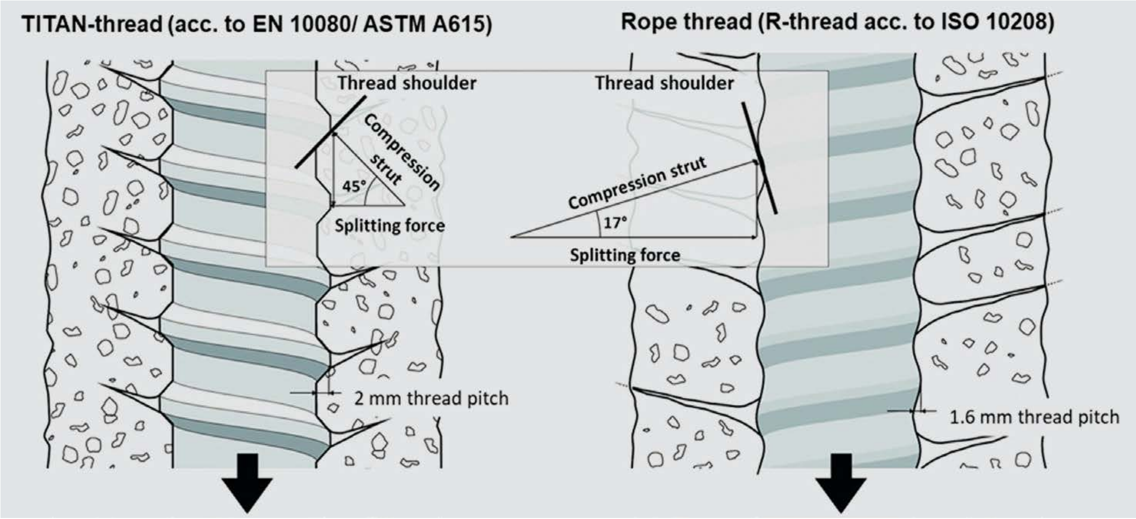

Fig. 3: Cracking pattern observed under tensile loading for Titan thread (left) and Rope thread (right) [12]

conditions and the cracks were marked and measured at each load step. The tests confirmed that the measured cracks were all less than 0.1 mm (0.039 in).

A separate test was also performed in Sweden were Titan threaded bars were exhumed and the cracking pattern studied (**Fig. 5**). The elements were cut into sample pieces and then impregnated with an epoxy with fluorescent properties. The epoxy was allowed to penetrate the samples and then viewed under UV light. A maximum crack width of 0.0 mm (0.00039 in) was measured in this experiment.

The uppermost part of the image represents the grouted body closest to the reinforcement, where many microcracks were observed. As we move outward, away from the steel, the cracking is reduced and very few cracks extend to the edge of the filter cake (highlighted in red). The outermost layer between the red and blue boundaries represents the filter cake formed during drilling where a cement suspension with a high water content was used as flushing fluid which is very apparent under the UV lighting.

According to the National Technical Approval document of Titan, adequate grout cover needs to be provided, based on all the testing carried out to ensure that the corrosion protection is maintained over the serviceability life of the project.

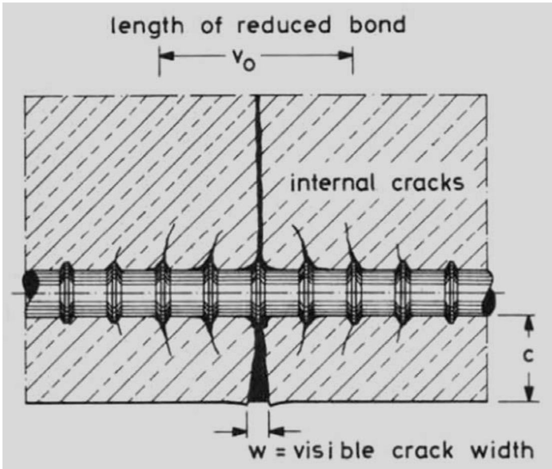

Fig. 4: Microcracks forming at every thread crest in reinforced concrete elements; only some cracks extend to the outer edge of the concrete [12]

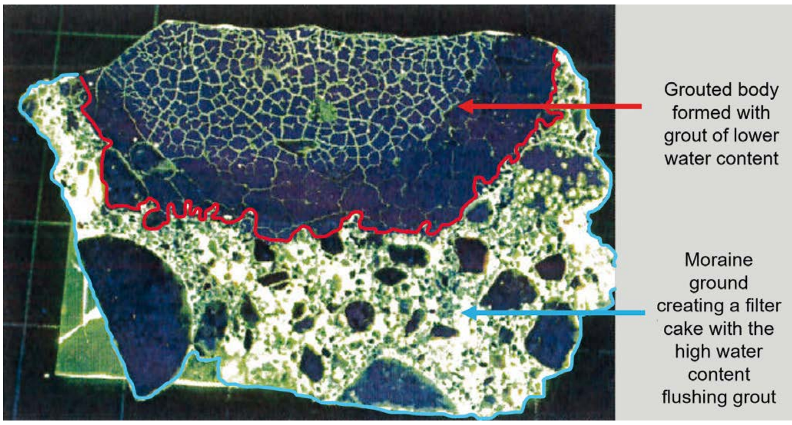

Fig. 5: Sample impregnated with an epoxy and viewed under UV Light

Conclusion

The industry has adopted the sacrificial corrosion technique as the main method for corrosion protection when it is in fact not at all applicable where coupled connections are considered for permanent installations. Many professionals assume the same method used for steel piles and sheet piles can also be utilized in micropiles without considering that the applications are quite different.

Although some of the codes and standards mention several methods of corrosion protection, it is the responsibility of the designer to determine the most appropriate method to ensure that the structural integrity is maintained through the service life of the elements. Allowing the bar to corrode – the protection method used for sheet piles or steel piles – also allows the threads to corrode. This can and will result in loss of the coupled connection and the structural capacity of the element.

The two most common thread types for micropiles, Rope threads and Titan threads, are both used in practice. The Titan threads, however, adopt the technique of grout encapsulation while the Rope threads adopt the method of sacrificial corrosion without considering grout encapsulation. In many instances a further barrier such as a galvanized coating is proposed as an additional corrosion protection measure.

The paper presents some of the test results for the Titan threads and also explains the concept behind the thread geometry. This thread type has been designed taking into account the well-known behaviour of reinforced concrete. Here, the use of grout encapsulation as an effective corrosion protection is more than adequate as long as the integrity and size of the grout body are accurately observed. However, very little evidence is available to justify the application of sacrificial corrosion in coupled elements as adopted in the case of Rope threads.

For the corrosion protection of Type E micropiles, sacrificial corrosion should not be the industry standard as this is not a method of corrosion protection but rather corrosion allowance. Many studies have been performed to show that an adequate grout encapsulation as well as the use of coatings such as galvanizing, and epoxy provide more than adequate corrosion protection in permanent applications. The use of sacrificial corrosion as a form of corrosion protection in permanent elements has yet to be thoroughly studied in terms of its long-term effects and the likelihood of decoupling after corrosion loss.

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Special Topic

Sustainability in Construction – Closing the Loop for Geosynthetics

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Geosynthetics have been used in various geotechnical applications for several decades now. Solutions with geosynthetics contribute to the conservation of granular materials and to a reduction in the transport of bulk materials. Current research work serves the purpose of improving ways in which geosynthetics can best be exploited.

Geotechnics • Geosynthetics • Responsibility • Circular economy • Research • Resource conservation • Recycling

1 Introduction

Geosynthetics (GSY) have been used successfully for decades in all geotechnical areas of earthworks and hydraulic engineering, and in the construction of transportation infrastructure and landfills. Here, on account of their operational and economic advantages, they are now recognised as established construction elements. This economic dominance is also reflected in the ecological sustainability of constructions incorporating geosynthetics. As an example, the leaner construction methods resulting from the use of geosynthetics can save the use of large quantities of granular material, of concrete and steel, and allow the use of locally available soils of inferior technical quality, so that mass transports of bulk materials are reduced. This results in considerable reductions in environmental stresses, such as reductions in CO_2 of up to 90 % compared to construction methods without geosynthetics, as well as reductions in other emissions (noise, tyre wear, etc.) [1, 2].

In Germany, approximately 1 billion square metres of geosynthetics (approx. 80 % nonwovens and 5 to 10 % each of wovens, geogrids and other geosynthetics) have been installed in the past 10 years. This corresponds to a total mass of around 290,000 Mg of plastic – with an upward trend [3]. The quantity of geomembranes used in landfill construction, tunnel construction and groundwater protection is of a similar order of magnitude and has not yet been taken into account here. At around 66 % by weight, polypropylene (PP) accounts for the largest share of raw materials used in geosynthetics, followed by polyethylene terephthalate (PET) at 26 %. Around 7 % of the products are made from high-density polyethylene (HDPE). The remaining one percent is accounted for by materials for special applications, such as aramid or polyvinyl alcohol. Because of the requirements for use which apply (including durability), high demands are made on the quality of the polymers involved.

While the majority of geosynthetics are designed for long-term use of 25 to 100 years, approximately 10 to 15 % are used in temporary constructions with a service life of < 5 years. Examples of such constructions are reinforced sub-base layers (**Fig. 1**) and woven tubes for sludge dewatering. Temporary base-course reinforcement under access roads and crane-erection areas (in Germany approx. 6.25 million m^2/a) [4] has become established as a standard construction method in the course of the expansion of renewable energies (wind farms, power lines, etc.) and is sometimes mandated by the authorities to protect the in-situ soil (e. g. on agricultural land).

Fig. 1: Exposed sub-base reinforcement of a temporary access road
Photo: FH Münster

In the next few years, an increased volume of deconstruction from structures with GSY is to be expected, as the first of the structures designed for more than 50 years will soon reach their scheduled end of life. These quantities will see an even greater increase in the future due to the increasing use of GSY.

With an average installed area of 100 million m^2/a in Germany, total masses of approx. 150,000 Mg/a of geosynthetics including adhering soil result from their deconstruction (assumption: weight increase GSY factor 4 to 6, depending on the application, see also **Section 4**). These have to be collected, processed, and separated in order to recycle the plastic fractions and other materials as far as possible.

The annual amount of geosynthetics to be disposed of in Germany is fairly small in comparison to other plastic waste, e.g. from the packaging sector. Specific to the respective deconstruction measure, however, these are usually high-quality plastics of largely homogeneous quality with a quantity of several megagrams per construction site, and these are thus predestined for higher-grade recycling. But in contrast to plastic packaging or other industrial products, appropriate return systems (deconstruction, logistics, processing, recycling) and successful approaches to closing the loop are not yet in place for products which have been in contact with the soil matrix over a large area.

For the product group geosynthetics, new approaches are also required for the following reasons:

- Greater focus in the EU and Germany on the resource use and consumption of construction products
- New requirements result from recycling quotas
- Prevention of uncontrolled quantities of plastics remaining in the environment after deconstruction

Another driver in this context, especially for German and European manufacturers, is the long-term supply of raw materials. It is foreseeable that sufficient quantities of raw materials (primary, but also secondary materials due to the competitive situation within the plastics sector) will not be available in the long term.

2 Current Situation and Challenges

Geosynthetic products must fulfil stringent requirements on durability. This is ensured, among other things, by particularly high requirements for the raw materials, and these are regulated in the harmonised application standards EN 13249 ff [5]. This currently excludes the use of recycled materials for reinforcement products and for products with a service life of more than 5 years, so that virgin material is generally used in the manufacture of geosynthetics. Material to be recycled arising within production is an exception and can be used to 100 % without pelletisation in the treatment process. Its use is limited elsewhere to 10 % without additional proof. Only for individual, selected applications do products already exist which are made using high-purity recyclates derived from deposit bottle recycling [6]. However, this R-PET is subject to very high demand for use in other product areas (e.g. packaging), so that prices are currently significantly higher than those of virgin material.

Regardless of the duration of the use phase, the geosynthetic product exhibits varying degrees of soil adhesion (minerality) after deconstruction, depending on the product type and the removal conditions. The disposal of these geosynthetic-mineral mixtures is currently carried out in waste incineration plants (WIP) due to a lack of alternatives (including take-back and processing concepts). In the context of hydraulic engineering, “disposal in the landfilled soil masses” has also been reported [7]. Disposal as secondary fuel, e.g. in cement plants, or recycling, is currently not practised. Due to the rather unfavourable properties of the waste for incineration in a waste incineration plant (ash content up to 45 % by weight, calorific value of the plastics up to 42 MJ/kg), the capacities are very limited and the resulting disposal costs high. During the monitoring of individual deconstruction projects, it became apparent that some waste incineration plant operators refuse to accept the material [3].

Table 1 gives an overview of the classification of the current procedure in terms of the waste hierarchy of the KrWG (German Closed Substance Cycle and Waste Management Act) as well as prerequisites for higher-value recovery aimed at closing the loop. Against the backdrop of strategies for resource conservation, and taking into account economic and ecological aspects of product responsibility in their entirety, the aim should be to close the loop as completely as possible for geosynthetics by re-using and recycling the materials (see also waste hierarchy § 6 of the Closed Cycle Waste Management Act [8]). To enable this, the following tasks need to be solved:

- In order to be able to re-use a geosynthetic, non-destructive and regulated deconstruction methods are required. Re-use is conceivable in particular for products used for only a short period.
- For recycling, there is a particular lack of return systems (appropriate deconstruction, logistics) and suitable processing technology for pre-processing the geosynthetics after deconstruction. These include suitable large-scale comminution technology and separation processes (wet/dry) for the soil adhering to the geosynthetics.

Table 1: Classification for different recovery options

Hierarchy in accordance with §6 KrWG	Prerequisites
Re-use (Objective of closing the loop)	▸ GSY undamaged ▸ Characteristic values clearly describable
Material recycling (Objective of closing the loop)	▸ Single-type plastic fraction, and GSY able to be processed to meet the acceptance criteria of the processing plant (piece sizes, purity, etc.) e.g. for PP, PET, HDPE ▸ Quantity of geosynthetic fraction sufficient for processing in batch operation
Chemical recycling	▸ Large-scale and more economically viable depolymerisation plants available beyond the demonstration scale ▸ Acceptance criteria (piece sizes, purity, etc.) definable and achievable in processing
Energy recovery	Chemical and physical specifications (e.g. heavy metals, chlorine content, calorific value, particle size) depending on the respective recycling plant (e.g. cement plant, solid-recover-fuels power plants)
Thermal treatment WIP (Current procedure)	Comminution specifications according to acceptance criteria of the waste-incineration plant, e.g. edge length < 1.0 m or piece size < 0.5 m^2
Disposal in soil mass (Current procedure)	In accordance with the German Technical Delivery Terms for Soil Materials and Construction Materials in Earthworks for Road Construction, 0.2 % by weight plastic content permissible

- For GSY, starting conditions for higher-value recovery are good, but there is a lack of appropriate recovery channels and business models. For recycling in recycling plants, the specifications of the respective plants must be observed. These specifications must be defined and guaranteed by upstream treatment processes, which have still to be developed, and by appropriate quality assurance systems.
- Digital building models (BIM) are one way of collecting and providing relevant information for closing the loop for GSY. However, there is currently a lack of consistent data management processes to link all the necessary information and make it available in a uniform manner.

Against this background, the Institute for Infrastructure, Water, Resources and Environment (IWARU – Working Groups Resources & Infrastructure) of Münster University of Applied Sciences conducted investigations into deconstruction (**Section 3**) and the material qualities obtained in the process (**Section 4**) and analysed and evaluated the accompanying processes. Using this as a basis, an overall concept was developed to fully close the loop for GSY (**Section 5**).

3 Studies on Deconstruction Processes

Within the R&D project "Implementation of product responsibility for geosynthetics by closing the loop – ProGeo (BMBF FKZ 033R336)", deconstruction was documented and analysed for a selection of geosynthetic products or constructions available on the market [3, 9].

The deconstruction procedures used were similar for all geosynthetics: After the surrounding soil had been rudimentarily cleared by machine to expose the geosynthetic (**Fig. 1**), the product was roughly folded and placed in a skip for transport to the waste incineration plant (**Fig. 2**).

If suitable attachments are available for the excavator, the process of removing the exposed geosynthetic layer can be done cleanly and quickly. A prerequisite for this is also properly instructed and trained personnel. If only a trench bucket is available, the geosynthetic will be bundled and large amounts of soil will remain trapped in the geosynthetic. A sorting grab will allow the geosynthetic to be exposed in a more filigree manner. In the case of more complex geometric conditions (e.g. in the facing area of a geosynthetic-reinforced earth construction, GRE), it may be necessary to remove the geosynthetic layer from the soil by hand. The speed of deconstruction with a sorting grab is essentially determined by the tensile strength of the material. In the case of nonwovens or products with low tensile strengths, tears can easily occur due to the point-loading engendered by the tips of the grab. The resulting fragmentation necessitates time-consuming hand-picking in the plastic residues remaining on the construction site. Products with a closed surface structure show considerable soil adhesion, especially in humid extraction conditions (**Fig. 3**).

Fig. 2: Deconstructed geogrid and nonwoven fabric in skip
Photo: A. Herold [9]

In the case of products with higher tensile strengths recovered under dry conditions, intact and clean sections of geosynthetic can sometimes be recovered over large areas by "pulling" the material free from the remaining soil (**Fig. 4**).

Growth of vegetation can lead to additional contamination of the geosynthetic. **Fig. 5** shows a geogrid from the facing area of a GRE. However, sections like this tend to have a relatively small area compared to that of the overall construction.

4 Investigations into Material Quality and Potential for Re-use

Various investigations were carried out on material samples obtained during the deconstruction work, and

Fig. 3: Irregularly torn and soiled nonwoven fabric haphazardly arranged after deconstruction
Photo: FH Münster

Fig. 4: "Pulling free" the geosynthetic layer with sorting grab
Photo: FH Münster

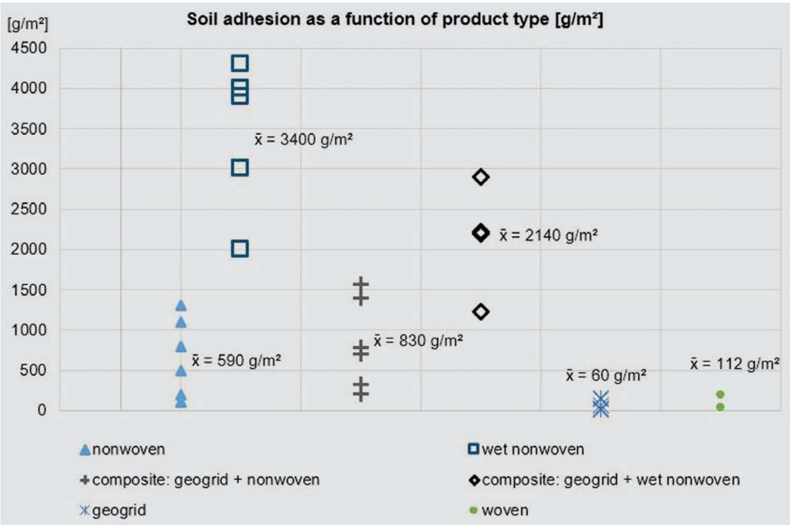

Fig. 6: Soil adhesion as a function of product type [g/m^2]

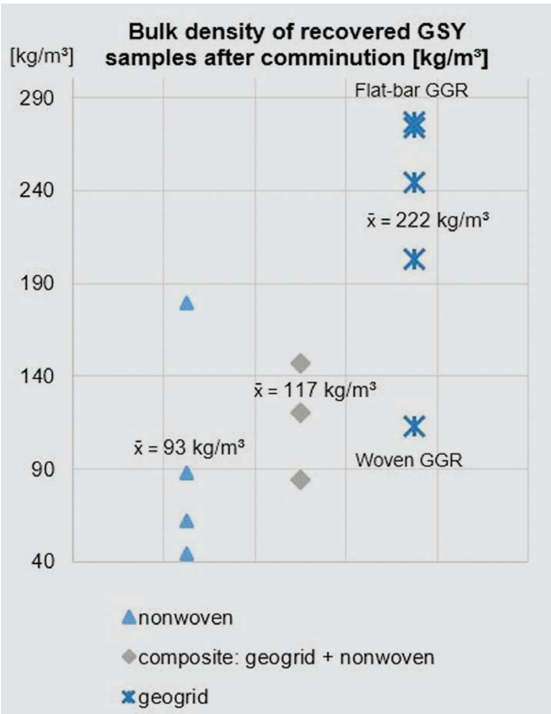

Fig. 7: Bulk densities of recovered GSY samples after comminution [kg/m^3]

Fig. 5: Overgrown geogrid and nonwoven from the facing of a reinforced-soil structure
Photo: FH Münster

these allow statements to be made regarding further use of the material emanating from deconstruction.

4.1 Mass per Unit Area and Bulk Density (after Comminution)

To quantify the soil adhesion, the masses per unit area were determined on deconstructed geosynthetic samples in accordance with EN ISO 9864 [10]. In addition, for products with nonwoven (content), saturation by storage in water was carried out to simulate the effects of humid extraction conditions. The mass of mineral adhesions results from the difference to the declared mass per unit area of the virgin material. **Fig. 6** shows the soil adhesion per square metre found in the product groups tested. It was apparent that especially nonwovens and composites with a nonwoven content had significant adhesions and were particularly sensitive to moisture during extraction. In comparison, wovens with a smooth surface and geogrids with an open structure exhibited only low adhesions.

The material adhering led to an increased abrasiveness, which is particularly relevant in downstream comminution processes, which are usually obligatory in the subsequent disposal route. Initial comminution trials in the technical centre of the IWARU (Institute for Infrastructure Water Resources Environment) have shown that if the geosynthetic samples are inserted in a single layer, comminution can be carried out successfully. The samples did not wrap round the shredder shafts, and the cutting edges were not blocked.

Subsequently, the bulk density was determined on the samples which had been comminuted three times. This can be used to estimate transport capacities after comminution, and as a process parameter when planning further processing steps.

Fig. 7 shows an overview of the achieved bulk densities as a function of the product type. In the case of the geogrids (GGR), the bulk density achieved was influenced in particular by the manufacturing process. Woven geogrids tend to have lower bulk densities than flat-bar geogrids. The bulk densities for nonwovens and nonwoven+geogrid composite products were of a similar order of magnitude.

4.2 Material Identification and chemical Parameters

Since a clear product identification was no longer possible for some samples after deconstruction, differential scanning calorimetry (DSC) was carried out to determine the polymer type used. This allows the characteristic melting points of a polymer to be used to infer its type. The German Guidelines for the Use of Geosynthetics (M Geok E) also require this test method as a control or incoming construction-material test to determine the identity of a sample [11]. With the help of DSC analyses, the polymer type of the unknown samples was able to be determined.

In addition, the samples were analysed for parameters (including calorific value, ash content, chlorine, heavy metals) which are relevant to co-combustion in cement plants or refuse-derived coal-fired power plants according to the BGS Quality Association for Derived Fuels and Wood Recycling (Gütegemeinschaft Sekundärbrennstoffe und Recyclingholz) [12]. **Figs. 8 and 9** show the results for ash content and calorific value depending on polymer and product type.

The significant granular adhesions in recovered nonwovens or composite products with nonwoven content are reflected in the high ash contents (virgin material approx. 0 to 1 % by weight). These granular deposits are detected here as non-combusted residue.

Despite the comparatively high ash residues, the calorific values of all samples are considerably above the calorific values suitable for waste incineration plants (approx. 8 to 10 MJ/kg), so that GSY can only be added there in doses. Energy recovery from the deconstructed GSY would therefore be possible in principle. However, this requires upstream processing in which the respective specifications (e.g. with regard to particle size and ash content) of the co-combustion (e.g. RDF power plant, cement plant) are achieved.

4.3 Reduction of Adhesions

Index tests were carried out to estimate the processing effort required to reduce granular adhesions. For this purpose, samples collected from construction sites were first comminuted (3 passes / piece size < 15 cm). The material was then dried until the mass was constant. The drying process itself caused the first soil particles to detach from the geosynthetic. Subsequent dry sieving led to a reduction in soil adhesion of between around 20 and 30 % by weight for heavily contaminated samples. The following wet sieving with a defined amount of water reduced the soil components by a further approx. 5 to 18 % by weight. **Fig. 10** shows an example of a heavily soiled nonwoven sample before and after the cleaning tests.

Fig. 8: Ash contents of recovered GSY samples [% by weight]

Fig. 9: Calorific values of recovered GSY samples [MJ/kg]

Fig. 10: Nonwoven fabric sample before and after partial removal of adhering soil
Photo: FH Münster

The success of cleaning is clearly visible, but also limited. To achieve the specifications for mechanical recycling, a significantly greater processing effort is required.

4.4 Maximum Tensile Strength

An important aspect when evaluating the possibility of re-using, after deconstruction, products with a reinforcement function which have previously been temporarily used is their tensile-strength behaviour. The tensile-strength behaviour of apparently undamaged and coherent pieces of sub-base reinforcement recovered during deconstruction was determined according to DIN EN ISO 10319 [13]. The samples tested had been installed for approximately 4 to 10 years. Values similar to those of new products were measured.

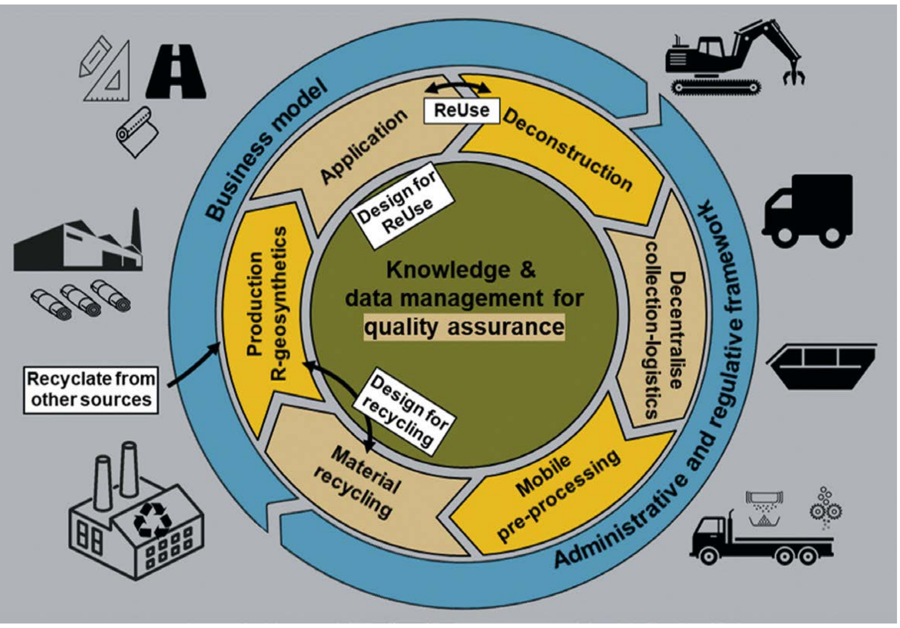

Fig. 11: Concept for closing the loop for geosynthetics
Graphic: FH Münster

5 Closing the Loop – a Concept for Geosynthetics

To be able to meet future challenges in the use of GSY at different levels (including administrative requirements, raw-material supply, social acceptance), the aim should be to close the loop completely (**Fig. 11**). To achieve this, new structures need to be created and optimisations made at all stages of the entire life cycle; this will increase added value.

Thus, optimisation with regard to re-usability (design for re-use) and recyclability (design for recycling) must start in the development phase of the GSY. Here, for example, the tensile strengths required for non-destructive deconstruction must be taken into account and material composition and methods allowing rapid material identification need to be developed. The re-use of selected geosynthetics – there is considerable potential here, e.g. in the area of temporary sub-base reinforcement – will allow additional reductions in the use of new material. If deconstruction processes are optimised (including by further developing existing attachments for construction machinery), re-usable products can result. Re-use must be limited here to a specified number of usage cycles, as the multiple use of the products is likely to cause mechanical damage. If geosynthetic products cannot be re-used, the material must be sent to a decentrally organised collection-logistics facility to undergo mobile pre-processing. For this purpose, mobile pre-shredding and cleaning stages need to be conceived and developed. The aim should be to carry out this pre-processing at strategically located interim storage sites for deconstructed geosynthetics. The objective here should be to achieve qualities (purity, piece size, etc.) that enable further processing in material recycling plants (designed for predominantly unmixed plastic waste (PP, PET, PE-HD, etc.)) (used in batch operation). In consultation with the recycling companies for the respective plastic fraction, the necessary specifications need to be defined and the decentralised treatment process coordinated accordingly. The secondary raw materials obtained can be incorporated into the new production of geosynthetics, so that manufacturers can be assured of long-term raw material availability. Complete substitution of virgin material is not yet feasible in the medium term, partly due to the long usage time of the products and the increasing production volumes. However, the approach taken here will create conditions which ensure maintenance of the strict quality standards that apply to geosynthetic feedstock in the EU in the long term. Necessary adaptations to cater for the use of secondary raw materials in the standardisation specifications need to be developed and introduced into the respective committees.

A complete closing of the loop for GSY can only be implemented efficiently if all necessary information is available digitally in a consistent and transparent manner based on open standards for all parties involved. For the selection of appropriate deconstruction methods as well as the re-use of geosynthetics, this information must be provided on a project-specific basis. On the one hand, the knowledge of the individual technical processes must be formalised and made testable so that a statement can be made in terms of environmental compability and economy on the basis of current data of a building and product. On the other hand, the data must be recorded and managed over the entire life cycle of the building. This information can be linked and stored with the digital building model in the form of material, product and condition passes. The digital availability of this information based on knowledge bases and digital twins also enables detailed life cycle assessment for the GSY. A business model to be developed and adapted for this field of application can support manufacturers in assuming their responsibility over all life cycle phases of their products. Thus, initial imputed calculations show the potential for higher-value recovery in the shape of mechanical recycling. The increased demand and improving revenues for PP and PET from recycled material thus open up significant financial scope for further processing and recovery.

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Special Topic

On the autogenous Healing of Cracks in waterproof Concrete Structures – Experiences in the Field and Conclusions drawn

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Structural planning engineers usually refer to EN 1992-3 when designing watertight concrete (WU concrete) structures such as basements, tunnels and water tanks. This standard can be interpreted in such a way that continuous cracks (separating cracks) are admissible. However, continuous cracks of between 0.05 and 0.20 mm in width are only acceptable provided they heal within a short space of time. Without this self-healing process steel-concrete structures are at risk of reinforcement corrosion and the structural integrity of the system may well be compromised unless suitable countermeasures are put in place. The following paper seeks to explain the causes of such cracks and the self-healing mechanisms at work. Practical examples are presented showing the serious consequences that can result for waterproof structures when wrong assumptions are made at the design stage about the self-healing properties of cracks.

Tunnelling • Geotechnics • Underground • Concrete technology • Waterproof concrete structures • Planning • Sealing • Structural stability • Damage • Injection • Geomembrane

1 Introduction

In the field of structural engineering waterproof concrete (WU concrete, WU is short for 'wasserundurchlässig in German language) WU structures such as basements, tunnels and water tanks that are subjected to water pressure from one side are frequently designed and built using EN 1992-3 'Eurocode 2: Design and construction of steel-concrete and prestressed-concrete structures - Part 3: Liquid retaining and containment structures' [1].

When referring to Section 7.3.1 of EN 1992-3 it could be assumed that water-bearing cracks are admissible for water retaining structures in conformity with impermeability class 1. Many planning engineers therefore believe in good faith that separating cracks with a width of between 0.05 and 0.20 mm are acceptable depending on the hydraulic gradient (**Fig. 1**). However, this assumption only applies if the continuous crack effectively heals within a relatively short space of time. This is referred to as autogenous healing or self healing. Whether or not the cracks heal themselves will nevertheless depend on various requirements and conditions.

Unfortunately these cracks do not always heal by themselves in practice. Steel-concrete structures that are affected in this way are therefore at risk of premature reinforcement corrosion. This can prove serious enough to compromise the structural integrity of the system unless appropriate counteraction is taken, such as effective sealing measures using geomembranes or systematic injection.

2 Problem Definition

Waterproof structures (WU structures) are now widely used in the construction industry, with basements and cellars, tunnels, deep-level underground stations, water tanks, water canals, rainwater retention basins and swimming pools being designed and executed for watertightness. Here it is important to comply with the relevant planning principles and also to ensure that the materials selected are up to the task.

According to DIN 1045-2 [2] concrete is considered to be impermeable to water (concrete with a high resistance to water penetration) when it has a water-cement ratio of below 0.60 (for component thicknesses of up to 40 cm), a cement content of at least 280 kg/m^3 and a minimum compressive strength of C25/30. Neither DIN 1045-2 nor the WU guideline [3] requires special additives or other admixtures to be used for the manufacture of waterproof concrete. A structure can also be said to be impervious to water when water penetration due to cracks, joints, fitted components and infiltration is minimal or negligible.

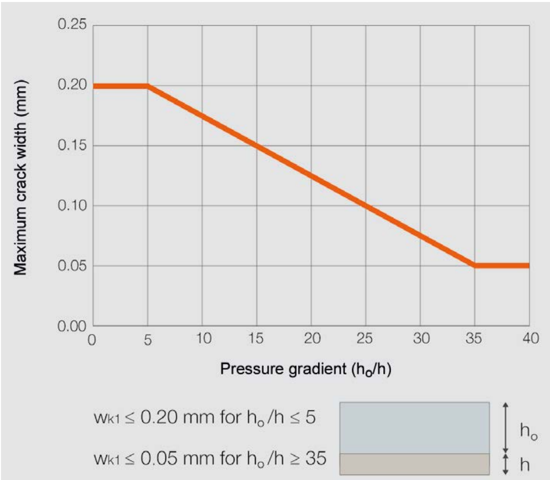

Fig. 1: Admissible crack widths for impermeability class 1 and self healing of cracks according to EN 1992-3 [1]

Source of the figures: COWI A/S, unless otherwise indicated

The design provisions for WU structural elements are regulated in standards such as EN 1992-3 [1]. According to this standard any cracks that are expected to extend across the entire thickness of a component (separating cracks) are to be limited to a width of w_{k1} (impermeability class 1). The values for w_{k1} can differ from country to country and are laid down in the respective National Annex. The recommended values for WU elements are conditional on the pressure gradients as a ratio of the pressure head of the water h_0 to the component thickness h (**Fig. 1**). For h_0/h values of ≤ 5 the w_{k1} will be 0.2 mm and for an h_0/h value of ≥ 35 the w_{k1} will be just 0.05 mm. In the range in between a linear interpolation will apply. This limitation of the admissible crack width should result in the autogenous healing of these cracks within a short period of time. An important factor for the self-healing process is the formation of calcium carbonate crystals (calcite) in the crack, this preventing any further water penetration.

2.1 Restrained Stresses as a main Cause of separating Cracks and Leakage

In practice, separating cracks that can lead to water permeability mainly occur in association with restrained stresses in early-stage concrete. A typical cause of such restrained cracks is the release of heat of hydration, a common example of this being the constraining force arising in walls when they are concreted on to a previously constructed foundation slab as part of a separate operation. Other influences that can generate restrained stresses, and hence lead to separating cracks in concrete, include concrete shrinkage, seasonal and daily changes in temperature and differential settlement.

This raises the question of what is to be done if these water-bearing separating cracks do not heal by themselves in a short space of time. The application of impermeability class 1 assumes that the cracks will heal completely and rapidly become permanent. Otherwise there is likely to be durability problems. However, autogenous healing does not take place on all occasions. In such cases the conditions laid down for impermeability class 1 are not met (**Fig. 2**). Yet when there is evidence of leakage and wet patches the conditions imposed by impermeability class 1 are still met provided the cracks then heal by themselves in sufficient time. It is therefore legitimate to ask whether the current criteria for impermeability continue to be meaningful or should be revised.

Fig. 2: Leaking cracks in the floor slab of a parking level
Source: Bodo appel, WEBAC

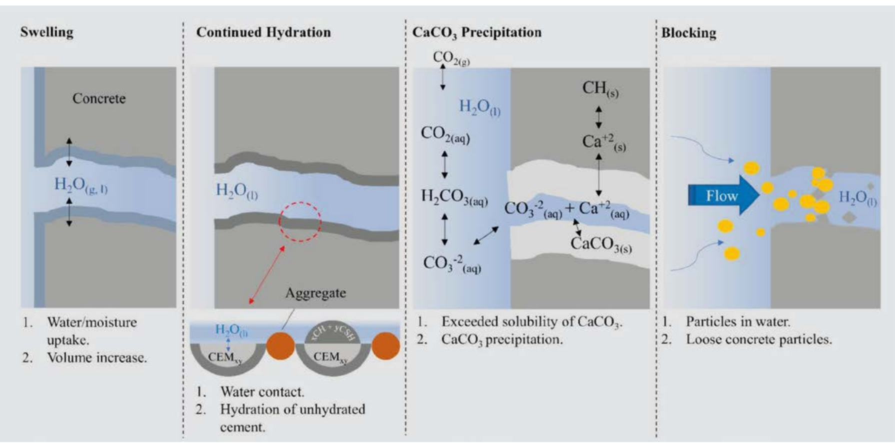

Fig. 3: Causes of self healing in separating cracks [4]

2.2 Autogenous Healing of Separating Cracks

The boundary conditions that are relevant for autogenous healing therefore play a very important role. The self healing of separating cracks is a complex chemico-physical process that is mainly caused by the precipitation of calcium carbonate crystals in the crack (**Fig. 3**). The dissolution of carbonic acid in water results in the formation of bicarbonate (HCO_3^-) and this in turn combines with the calcium ions (Ca^{2+}) to form water-insoluble calcium carbonate ($CaCO_3$), as shown in the simplified chemical equation:

$$Ca^{2+} + 2HCO_3^- \leftrightarrow CaCO_3 + CO_2 + H_2O \quad (1)$$

In the 1990s the Institute for Building Materials Research at the RWTH Aachen (ibac) carried out a research project into the autogenous healing of cracks. The results of this study were presented by the author as a dissertation [5]. The research work investigated a range of factors that could affect the self-healing process, namely:

- **Concrete:** type of aggregate, cement content, filler material and age
- **Water:** hardness, pH value, pressure and temperature
- **Cracks:** width, length, branching, movement and roughness

The tests were conducted on small sample pieces measuring 20 x 20 x 20 cm^3 and containing a continuous vertical crack and on larger specimens measuring 250 x 100 x 40 cm^3 containing several continuous cracks. The samples were subjected to water pressures of between 0.25 bar (equivalent to a water column of 2.5 m) and 1.5 bar (equivalent to a water column of 15 m). As expected, the rate of flow increased in line with the width of the crack. However, it was also found that after a certain period of time the flow would also come to a halt (Fig. 4). In the case of cracks measuring 0.1 mm in width this would happen after about 150 h (or around 6 days) and for cracks 0.2 mm in width it would take place after about 440 h (around 18 days). The same effect was not evident for cracks measuring 0.3 mm in width even after some 450 h (about 19 days) had elapsed. This suggests that a long-term leakage can be expected in the case of cracks measuring 0.30 mm and more. The tests also revealed that even when using soft water of 4 °dH (units of German hardness) the autogenous healing process was comparable to that observed with hard water of 27 °dH. From this it could be concluded that water hardness did not affect the outcome and that even soft (lime-poor) water contained enough carbonate to trigger the self-healing process. The volume of flow in the dynamically stressed crack also declined over time but was generally higher than in the statically stressed crack. The calcium carbonate precipitation that is the main cause of the self-healing effect is primarily dependent on three factors, namely temperature, water pressure and pH value. The type of cement and aggregate and the ultrafines content, on the other hand, had no influence on the self-healing properties. Various other findings can be obtained from the aforementioned dissertation, which has been published in issue 455 of the Handbook of the DAfStb (German Committee for Reinforced Concrete) [5]. On the basis of these results a set of practical application tools was developed that were also used for the provisions contained in Eurocode 2 (and hence EN 1992-3) and in other international guidelines (e.g. DAfStb WU guideline [3], Ciria C766 [6]).

2.3 Reinforcement Corrosion in water-bearing Separating Cracks

Any risk assessment of reinforcement corrosion in water-bearing separating cracks will differ fundamentally from similar analyses of reinforcement corrosion in 'normal' separating cracks, i.e. cracks that are not water bearing. Unfortunately some of the specialists working in this field are unaware of this fact.

With continuous, water-bearing separating cracks a special type of corrosion cell occurs that has a confined anode at the steel in the crack zone and an extensive cathode that encompasses the entire steel reinforcement on the air side. This extremely unfavourable anode-to-cathode area ratio produces high corrosion rates at the concrete-reinforcing steel as soon as the steel very quickly begins to oxidise. This means that the reinforcement corrodes directly when the steel comes into contact with water. The reason for this is that unlike the situation in 'normal' cracks that are not water bearing the water passing through the crack prevents the formation of a passive layer that can provide alkaline protection for the reinforcement.

In the case of water-bearing separating cracks the tendency for reinforcement corrosion to develop as a function of the chloride content of the water will be all the greater, the higher the salinity. However even in the case of fresh water (i.e. drinking water) the steel will also corrode in water-bearing cracks. If it is assumed, when dimensioning WU structural components, that the autogenous healing of cracks will take place, and if continuous cracks are admissible but do not of themselves heal fully and permanently, then reinforcement corrosion can be expected to occur and this will compromise the durability and in some cases even the structural integrity of the component in question.

The special corrosion mechanism at work in the case of water-bearing (i.e. non self-healing) separating cracks can be confirmed by numerous cautionary examples and can be recognised in the form of corrosion products occurring on the surface of the concrete and at corroded reinforcing steel (Fig. 5).

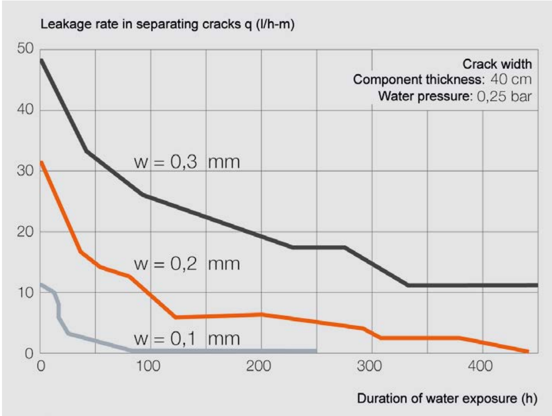

Fig. 4: Typical leakage rate for separating cracks under water exposure and with self healing

3 Practical Examples from the Middle East

COWI A/S has for many years acted as a global consultant for projects involving water-impermeable concrete structures and has acquired expertise from many ventures of this kind, including in Bahrain, Denmark, Qatar, Oman, the United Arab Emirates and Vietnam.

Fig. 5: Reinforcement corrosion in a non self-healing water-bearing separating crack in a WU structure

3.1 Hospital with a two-storey Underground Car Park in Abu Dhabi in the United Arab Emirates

One example from Abu Dhabi in the United Arab Emirates illustrates how the special environmental conditions prevailing in that region can affect structural components. This kind of environment makes very high demands on material durability and creates some of the most aggressive ground and groundwater conditions to be found anywhere in the world. The salinity is between 10 and 12 %, in other words four or five times higher than that of the Baltic Sea. Soil temperatures can be as much as 30 °C and air temperatures in the summer can reach 50 °C, while the huge variations between the daytime and night-time temperatures promote dew and condensate formation. The groundwater has a sulphate content of up to 5,000 mg/l – a level never experienced in Europe.

Water was found to be entering the basement of a five-storey hospital in Abu Dhabi (**Fig. 6**). The static calculation had assumed or anticipated that in such cases the separating cracks would heal of themselves. But this self healing did not take place. The two-storey basement car park initially gave no indication that anything was amiss. Photos and drawings of the as-is status, as well as those produced at the time the geomembrane was laid with pile head penetration, at first also appeared to be quite innocuous. The design criteria employed in this case were based on EN 1992-3 (impermeability class 1), according to which cracks of up to 0.2 mm in width are admissible on condition that a self-healing process takes place. For 'safety' reasons a geomembrane-type sealing barrier was installed beneath the floor slab and around the walls. However, this failed to perform its intended function, as was soon to become apparent after the construction was completed.

The solid floor slab was concreted in five stages. The chosen concreting sequence meant that the restrained stresses, and hence the risk of continuous restrained cracks, would be greatest in the very last concreting section (panel 5). Shortly after concreting had concluded a number of continuous cracks were found in this area, particularly in the vicinity of the integrated pile heads, which only served to increase the forces at play. Other issues arising during the first three or four years after construction work began included concrete spalling, defects to the concrete bond, corrosion products such as rust stains and water marks on the upper surface of the floor slab, ineffective sealing of the geomembranes and further separating cracks.

As a result of all this COWI was commissioned to carry out an inspection and to assess the state of the structure. This included a visual impression of the entire basement level with its water penetration problem, the identification of strategic sites for taking drill samples, a study of these samples and an analysis of the causes of the cracks, and ultimately the submission of proposals for the repair work. During the inspection it was found that the rebars for the upper reinforcement of the floor slab exhibited worrying signs of degradation just four years after construction began. The upper reinforcement layer could therefore no longer be considered in the overall calculations. As there had been no self healing of the cracks penetration by the saline groundwater has caused the concrete to become extremely damp. The concrete mix and the additional use of expensive 'waterproofing materials' had also proved completely ineffective.

The crack injection work that was undertaken prior to the inspection had not been successful. The building contractor had carried out several tests aimed at injecting grout into the cracks. This involved the use of different injection materials which, however, were not able

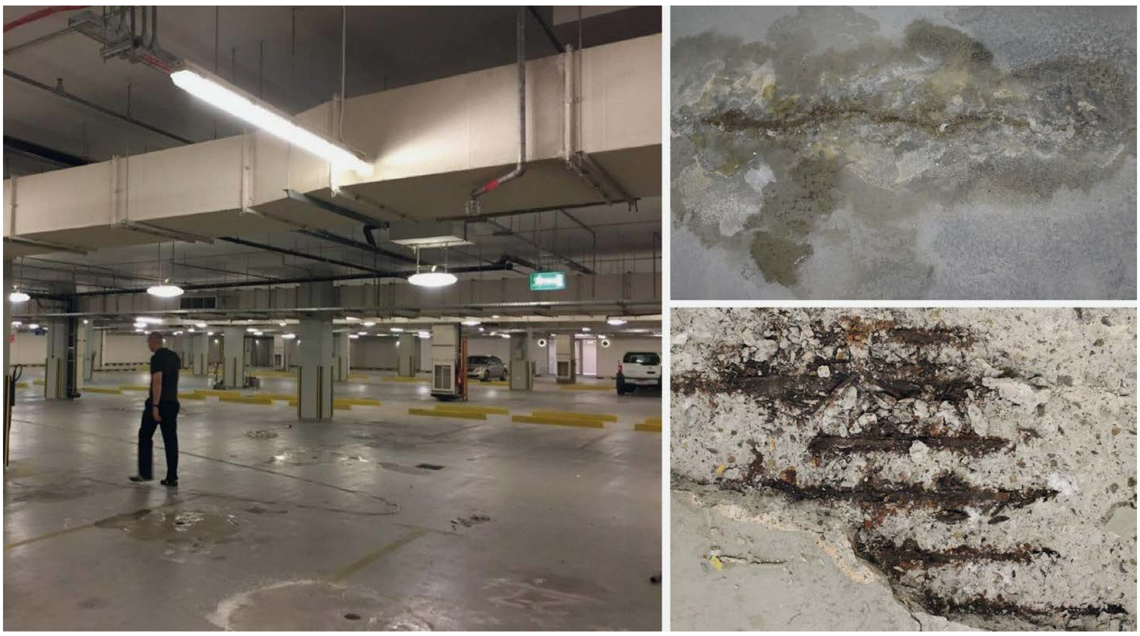

Fig. 6: Floor slab of an underground car park in the United Arab Emirates with non self-healing water-bearing cracks and heavily corroded reinforcement

to prevent the water intrusion. The failure of the injection operation can be attributed, among other things, to the fact that a specialist company had not been commissioned to undertake the injection work and that unsuitable injection materials had been used. Under these conditions it was doubtful that the basement floor could undergo a viable and successful repair.

3.2 Office Block Complex with a three-storey Underground Car Park in Doha, Qatar

Another example comes from the Petroleum District of Doha in Qatar where the environmental conditions are just as aggressive as in the previous example from Abu Dhabi. The Petroleum District comprises ten office blocks 220 m (47 stories) in height and a three-storey underground car park capable of accommodating up to 5,000 vehicles. Construction work on this complex began in 2011 and was finally completed in 2016. The building was designed for a service life expectancy of some 50 years.

The basement floor was built using a 750 mm-thick floor slab resting on 2,500 piles 1,500 to 5,000 mm in diameter. The side-walls around the basement are 400 mm thick and are concreted up against diaphragm walls. Sealing is provided using a loosely laid geomembrane designed to allow subsequent injection. The maximum water pressure is 1 bar or a 10 m column of water. The underlying design philosophy is based on BSI British Standards – BS 8102:2009 'Code of practice for protection of below ground water structures against water from the ground' [7], which allows separating cracks of up to 0.25 and 0.30 mm. A watertight geomembrane (type A according to 6.2.1 General – Barrier protection) was also installed.

No apparent problems were encountered during the construction phase when the groundwater was being continuously managed. However, in 2012 the first water ingress in the basement took place immediately after the water pumps had been shut down. Injection work undertaken in 2013 and again in 2017 proved unsuccessful. Signs of corrosion damage to the reinforcement were already evident in 2018. The cracks in the structure also failed to heal themselves and, moreover, the geomembrane seal failed to function as intended.

4 Practical Examples from Europe

The problem of cracks failing to heal themselves is by no means restricted to the Middle East. Indeed the following examples show how European projects can be similarly affected:

- Lock chamber operated by the Federal Waterways Engineering and Research Institute at Karlsruhe, Germany
- Sprinkler system at the 'Alexa' shopping centre on the Alexanderplatz in Berlin, Germany
- Kvaesthus Project in Copenhagen, Denmark

At the Kvaesthus project in Copenhagen, for example, the external walls of the basement space were provided with a geomembrane-type sealing system. When the walls soon started to leak no permanent self-healing process took place and as a result the client called for the cracks to be sealed by injection. The cost of the subsequent injection and repair work was put at some € 2.2 million.

Another practical example of self healing in action is provided by the Great Belt Tunnel in Denmark (a cut and cover tunnel segment), which was opened in 1997/1998. Here the effects of self healing were confirmed by drill core analysis and also revealed by taking concrete thin sections from the areas in question. This example shows that self healing can take place in reality, though a permanent and complete sealing of the entire crack cannot be taken for granted. The cracks were therefore successfully injected with an acrylate gel more than 20 years ago and have remained watertight ever since.

5 Conclusions

The examples cited above show that when designing WU (waterproof concrete) structures the actual project-specific circumstances have to be considered very carefully and precisely if the complete self healing of cracks is to be more than mere wishful thinking.

From the given accounts of problems of this kind and descriptions of the damage incurred it can be seen that the requirements and/or assumptions for impermeability class 1 and the crack widths for which autogenous healing can be applied according to EN 1992-3 are open to debate and should possibly be removed from the guidelines. However, this begs the question of exactly how separating cracks are to be prevented in the first place. Containing the premature formation of restrained cracks has become a pressing issue. The development of such cracks can be controlled by taking the following measures:

- Maintenance of a low fresh-concrete temperature and use of concrete cooling in order to limit the temperature differences between the concreting stages
- Use of latent hydraulic materials such as fly ash and blast furnace slag in order to control the hydration process and the resulting heat build-up

Precautions should also be taken at the structural design stage to ensure that restrained stresses are kept to a minimum. These structural measures may include using liners below the floor slab and excluding any fixation of the floor slabs in the pile foundations. The introduction of controlled crack joints with designated injection points is another expedient measure. The use of a geomembrane-based sealing system, concrete injections or a permanent drainage system should also be considered. The Danish standard DS EN 13670 'Execution of

Special Topic

concrete structures' [7] also constitutes a promising approach. This calls for the temperature difference to be limited to a maximum of 15 °C when new concrete elements are being added to existing structures in order to prevent the formation of continuous restrained cracks.

In order to arrive at an effective geomembrane solution it is vital to adopt a critical approach to the quality control process during the execution phase. Acceptance criteria have to be carefully matched to the intended usage. As the given examples show, even the best geomembranes will not function properly if the execution is defective.

Injecting cracks with a filler material is often the last of the options to be considered when it comes to controlling water penetration in WU structures. In this case procedural expertise and meticulous planning are the keys to success. Crack injection is one particular field where a range of methods and materials is available according to the performance requirements. The materials in question include acrylate gels, epoxy resins, polyurethane resins and ultra-fine cements. Such injection measures should in general only be executed by specialists and must always be carried out using the best available technology (e.g. in accordance with the ABI injection sealing instructions as issued by the STUVA research association [9]).

6 References

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The Emscher Restoration Project: a real Success Story for Germany's most populous State

Dr.-Ing. Eckart Pasche, Willich, Germany

For nearly a hundred years the Emscher served as an open wastewater channel that helped to kick-start the development of the Ruhr basin as a centre of industry in North Rhine-Westphalia. The river has now been cleaned up and has been completely free of sewage since the end of 2021. The Ruhr Museum in Essen, Germany has been holding special exhibitions to celebrate the event.

Geotechnics • Tunnelling • Hydraulic engineering • Renaturation • Environment protection • Exhibition

After more than a hundred years the Emscher, which until the early 1990s was considered the dirtiest river in Germany, is again free of wastewater and sewage (**Fig. 1**). This achievement is the result of a renaturation and infrastructure engineering project that has cost a lot of money and taken years to complete.

During the 1860s, as coal mining gradually moved away from the Ruhr and northwards towards the Emscher, the surface terrain began to sink and this subsidence process created marshy bogland areas. The wastewater from the collieries and smelting works tended to collect here and putrify, this being augmented by sewage from the new housing settlements as the population of the area grew rapidly through the 19th century. While in 1818 towns like Essen and Dortmund had fewer than 5,000 inhabitants, by 1910 Essen had a recorded population of 294,653 and Dortmund 214,226. In 1901 this sewerage emergency created a typhus epidemic in Gelsenkirchen that resulted in the death of some 350 people. It was this crisis that prompted Robert Koch (1843-1910) to set up the Ruhr Hygiene Institute that same year.

It was this situation that also led to the creation of the Emscher Water Board Association in 1899. The problem it faced was that mining subsidence prevented the construction of underground sewers, as these would have been damaged by the ongoing strata movement. The Emscher river was therefore to serve as the coalfield's central waterway, with its tributaries being used as wastewater courses. The river and its side-streams were straightened and the bodies of water were enclosed within dykes that were supported with concrete walls. The days of flooding and disease were over – but the stench of the open sewer remained.

The northwards Migration of the Mines spells the End of Ground Movement

During the period between the northwards migration of mining towards the Lippe and the final closure of the coal industry in 2018 ground movements caused by mining subsidence had almost stopped entirely. This provided the Emscher Association with an opportunity to 'decommission' the old sewerage and drainage system. This meant that the old sewage ditches could be freed from wastewater step by step, their contents being channelled through underground pipes to the treatment plant. The course of the streams could then be reconfigured by way of a 'renaturation' process. The first in a series of projects commenced in 1982 with the Dellwiger river in Dortmund.

Fig. 1: In September 2022 Federal Chancellor Olaf Scholz planted the first grapevine along the banks of the Emscher in Castrop-Rauxel.
Photos: Emschergenossenschaft

The intergenerational project for the near-natural conversion of the Emscher River System was initiated by the International Architecture Exhibition Emscherpark (1989–1999). The entire Emscher watercourse system was subsequently reconstructed within the planned and budgeted timeframe of 1992 to 2021 at a total cost

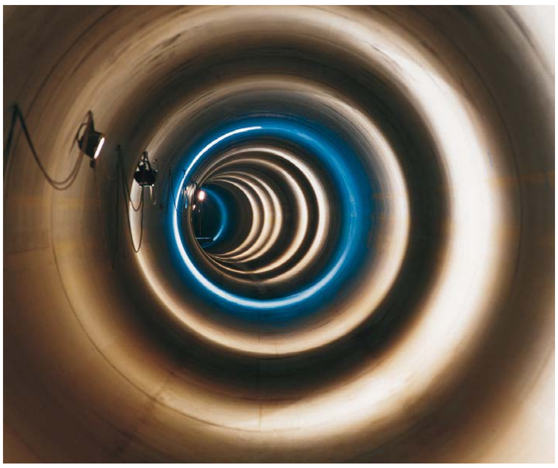

Fig. 2: Looking into the 51 km-long Emscher Interceptor (AKE)

of some € 5.38 bn. The Emscher Interceptor (AKE) – also known as the 'Emscher underground expressway' – is the reason why the Emscher river now runs clean and the local water courses have been restored to a near-natural state. The planning and construction of this key underground sewer, which is as much as 40 m deep in places, proved to be an engineering masterpiece (**Fig. 2**). The first sod for the new Interceptor was ceremonially turned on 11th September 2009. The AKE is some 51 km in length and runs from Dortmund-Deusen to Dinslaken.

Round-profile sewage pipes with diameters ranging from 1.60 to 2.80 m were laid along the eastern stretch of the Emscher while rectangular box profiles with an internal height of 2.45 m and an internal width of 2.25 m were used in the western section. The AKE's drainage gradient of 1.5 ‰ called for three pumping stations to be set up along the westerly flow at Gelsenkirchen, Bottrop and Oberhausen/Duisburg. The installation at Oberhausen-Biefang, which is Germany's largest sewage pumping plant, is equipped with ten pumps that can transfer the wastewater from a depth of 40 m at a maximum output of 16,500 l a second.

An Area that once housed a dirty Sewer will one Day be growing Vines

Some 436 km of sewer pipe were laid and nearly 329 km of watercourse ecologically improved prior to the final commissioning of the entire system at the end of 2021. On 1st September 2022 the Federal Chancellor Olaf Scholz travelled to Castrop-Rauxel to celebrate the conclusion of what was Europe's largest infrastructure project (**Fig. 1**). This location, which stands at the city boundary with Recklinghausen, will one day accommodate the region's largest vineyard, which will be contained within an entirely new recreation area. And the Chancellor marked this with a ceremonial planting of the first symbolic grapevine.

Scholz described the achievement as follows: '*The successful conclusion of this project stands as a shining example for similar initiatives in places far beyond the borders of Germany*'. He pointed out that what had been done there would be of enormous interest to other mining regions in particular and added that Colombia was also interested in adopting the Emscher model to restore the heavily polluted Bogotá River. There were even visitors present from Afghanistan, for that country still had hardly any water treatment plants to speak of and wastewater and sewage was simply allowed to seep away into the soil outside the towns and cities, thereby contaminating the groundwater. The Kabul River in Afghanistan was said to be even dirtier that the old Emscher had been.

The Emscher Association kept a photographic record of all its work from the very start of the project and this photo archive containing more than 40,000 glass plate negatives is now on loan to the Ruhr Museum. These show the course of the Emscher and its side-streams as well as the different construction sites. **Figs. 3 to 5** give some impression of the history of the area as documented in these photographic records.

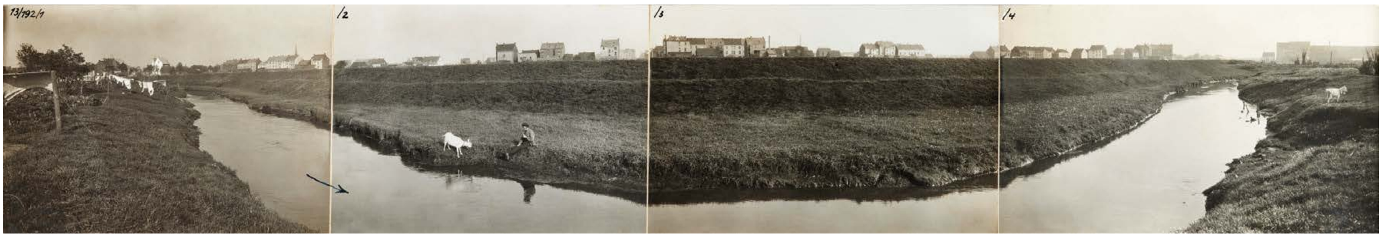

Fig. 3: Part of the old Emscher course as it was in 1908

Fig. 4: Constructing the Alte Emscher pumping station

Fig. 5: Diver at the Huckarde pumping station

Fig. 6: View of the trial section at Dortmund-Deusen
Photo: Jannis Reichard/Emschergenossenschaft

Fig. 7: 'Electric hog' in operation at a water treatment works

What is particularly striking are the panoramic views and comparative images that illustrate the 'before and after' effects of industrialisation. The collection not only records the transformation of the Emscher into an industrial river, along with the technical efforts and the heavy physical labour that were needed to bring this about, but also shows the massive changes that were wrought to the landscape as the river was 'rectified'. As a result the library also constitutes a photographic and socio-cultural treasure trove that traces in convincing fashion the residential and industrial development of the Ruhr basin over an entire century.

In the words of Heinrich Theodor Grütter, Director of the Ruhr Museum and Member of the Board of the Zollverein Foundation, '*The Ruhr Museum and the Zollverein Foundation have taken the provisional conclusion of the Emscher restoration project as an opportunity to stage two major exhibitions at the Zollverein World Heritage Site in the north of Essen where the Katernberg brook also makes the city part of the Emscher river system*'. More information on the second of the two special exhibitions can be found in the Info Box.

The renaturation process that has been under way in these idyllic riverscape locations has seen the variety of local species nearly triple in number from the 170 or so different types that were present in the early 1990s, with the result that some 500 different species have now returned to make their habitat along the Emscher (**Fig. 6**). Trout, cottids and sticklebacks have been present in the river for quite a few years and kingfishers – which an indicator of good water quality – are now just as home along its banks as are grey wagtails and beautiful demoiselle damselflies. But the famous 'Emscherbruecher', a wild breed of domestic horse, have died out completely and the water treatment plants now employ an 'electric hog' to do the rooting and rummaging (**Fig. 7**). The industrial era was only one episode in the life of a river. Today the Emscher is very much as alive and well as it once was. And nature has ultimately proved to be the winner.

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Special Exhibition: 'The Emscher. The pictorial History of a River'

The former coal washing plant at Zollverein colliery provides an imposing industrial backdrop for a special exhibition (due to run from 12.9.2022 to 16.4.2023) that presents the entire pictorial history of the Emscher from the pre-industrial days through the industrial age to the present-day ecological restoration of the Emscher river system.

Ruhr Museum
Zollverein UNESCO World Heritage Site
Gelsenkirchener Strasse 181
45309 Essen
Germany
For more information visit:
https://ruhrmuseum.de/

Pula Group's Graphite Project positions Tanzania in the World's Clean Energy Transition

Dr. Mary-Mildred Stith, The Pula Group, Dar es Salaam, Tanzania

Tanzania hosts world-class graphite deposits and the Pula Group leads with a profitable and socially responsible model for exploration.

Mining • Raw materials • Graphite • Tanzania • Energy transition • ESG

As the world embraces the clean energy transition and, with it, more environmentally-friendly transportation, the spotlight is on the mining sector. A November 15th, 2022 article in The Financial Times [1] estimates the current supply for natural graphite is 1.2 million tonnes; by 2035, the demand will be 7.2 million tonnes. Democratic mineral-rich stable African countries represent new options in the supply-chain if the world is going to meet its clean energy goals. Two potential partners for countries, like Germany, that want to be leaders in the clean energy space are Tanzania and The Pula Group (**Fig. 1**).

Pula holds four graphite licenses in the Ruangwa region (**Fig. 2**), home to Tanzania's richest graphite belt. Pula's operations in Tanzania provide a real life, compelling answer to the question: Who can provide the necessary resources to support Germany's goal of becoming the center of European battery production? The Pula-Tanzania tandem provides a solution to critical mineral supply chain issues and answers the above question based on five reasons:

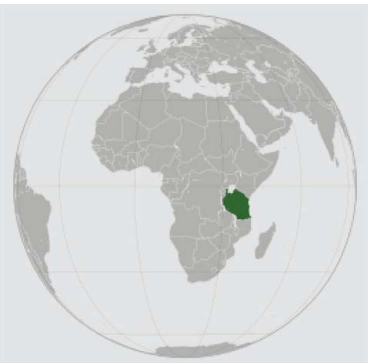

Fig. 1: Tanzania in a global context

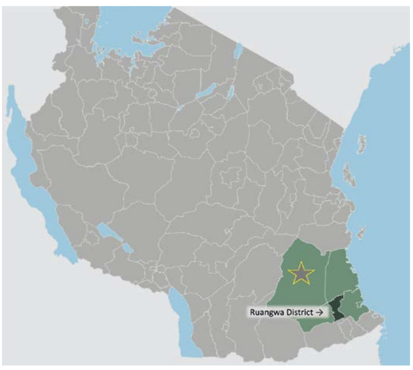

Fig. 2: License PL10332 starred in Ruangwa District, Tanzania

Fig. 3: Drilling exercise of PL10332

1. Extensive high-quality graphite reserves
2. Profitable and environmentally-friendly operations
3. A politically stable country
4. Germany knows Tanzania, Tanzania knows Germany.
5. Pula Group is establishing new ESG standards from the ground up.

Extensive High-Quality Graphite Reserves

Tanzania's southern graphite belt has some of the largest deposits in the world. The British Geological Survey recently commissioned a study on graphite deposits in Africa and Pula's graphite project was ranked the 5th largest in terms of total tonnage. Pula has prioritized one license – PL10332 – which has significant finds of 34 Mt of Indicated Resource and 62 Mt of Inferred Resource (Ni-43-101 compliant) (**Fig. 3**). Pula's resource profile of the project far exceeds the profile of projects in countries like China:

(i) The total graphitic carbon (TGC) ranges from 20.1 to 5.45, with an average TGC of approximately 9.5 %, exceeding viable deposits elsewhere in the world (2 to 4 %).
(ii) Forty percent of the flakes range from large to super jumbo and 30 % from medium to large, which command a premium price. The characteristics in terms of quantum and quality are exceptional. Pula recently commissioned a new round of metallurgical studies that achieves a graphite concentrate of 96 percent purity with traditional floatation techniques.

The high-quality graphite mineralization includes jumbo flakes with a near surface deposit with long-term potential. Pula's Ruangwa deposits are extensions of the Nachu graphite deposits. Regionally, Pula's graphite licenses are within the Usagaran (Mozambique belt) Proterozoic system. This system is principally defined by high grade (amphibolite grade) metamorphic rocks of both sedimentary and igneous origin, ranging from schists to gneisses, including marble, amphibolites, graphitic schist, mica and kyanite schist, acid gneisses, hornblende, biotite and garnet gneisses, quartzite and granulites that are overlain by Cretaceous sediments in the east and Karoo in the southwest. Structural trends of the Usagaran are mainly north south. Rocks in the Usagaran system are well known for hosting gold, nickel, copper, vanadium different gemstones such as tourmaline, red garnet, tanzanite, and the highest-grade coarse graphite flakes in the country. In light of the geological context, Pula is analyzing graphite tailings for other critical, high value commodities to further bolster strong project economics.

Profitable and environmentally-friendly Operations

The project is economical and environmentally sound. In Q4 2022, Pula secured next stage financing from an US venture capital firm and signed a MoU for offtake with a Singapore trading company. Pula has developed an exploration approach – The First Pit, First Plant – that is defined by generating revenue and value during exploration, while proving out the assumptions for full production. During exploration, value is generated by:

- Establishing mineral resource and reserves
- Selling offtake during the exploration phase, which incorporates a modular mine
- Proving techno-financial assumptions for a full production mine
- Generating tax revenue
- Prioritizing CSR (Corporate Social Responsibility) and social enterprise to benefit communities and countries
- Establishing ESG (environmental social governance) standards to guide the project from exploration to mine closure and rehabilitation

The economic indicators of 'First Pit, First Plant' on PL10332 are promising. Post-capital injection, Phase 1 will achieve production – 12,000 tonnes of graphite concentrate per annum – in approximately 12 to 16 months (estimated production Q2 2024). Phase 1 IRR (internal rate of return) is 58 %. The payback period is 25 months, with a Profitability Index of 309 %. The current NPV (net present value) is $89 million and a conservative estimate of the NPV at full production – 80,000 tonnes of graphite concentrate per annum – is $330 million.

Pula's model generates revenue in the first year of production, lays the foundation to secure debt financing for full production, and scales up the operation to reduce environmental, social, and financial risk.

A politically stable Country

Tanzania has a stable, democratic regime and is endowed with abundant natural resources. It is working proactively to provide an environment to attract companies to help develop those resources. In order to further stabilize the mining sector, the Tanzanian government has developed and implemented a comprehensive package of mining legislation, which emphasizes industrialization and local beneficiation. Key regulations include the 2019 Mining Act and Regulations, The Tanzania Extractive Industries Transparency Accountability Act 2015, the Finance Act of 2019, and the Mining Commission Guideline for Submission of Local Content Plan 2018 [2].

In addition to creating a conducive regulatory environment to make it possible for companies to operate profitably, Tanzania is also implementing important infrastructure improvements that are helpful as well. For example, in the Ruangwa region, where Pula's assets are located, the government recently completed road improvements that make transport from mine to port much more efficient and profitable (**Figs. 4 and 5**).

Germany knows Tanzania, Tanzania knows Germany

The author Stephen King is quoted as saying "Sooner or later, everything old is new again". Beginning in the 1890s, the first systematic prospecting missions in Tanzania were conducted by German geologists, such as: Lieder (1892), Stromer von Reichenbach (1896), Kossmat (1897), and Bornhardt (1898, 1899). The first gold mine in Tanzania, the Sekenke Mine (Sachsenwald), was established in 1909. Since then, the Geological Survey of Tanzania has continued providing geo-scientific data, information and services for national development. Evidence of this progress and potential is that 94 percent of Tanzania has been geologically mapped and published at various scales. 100 percent of Tanzania has low resolution airborne geo-

Fig. 4: License PL10332 roughly 225 km from the deep water port of Mtwara

Fig. 5: Aerial view of Mtwara Port, 1 million tonnes of capacity

Special Topic

About Pula Graphite Partners (PGP)

- Pula Graphite Partners (PGP), a subsidiary of the Pula Group (U.S.), holds 4 graphite licenses in Tanzania, 230 km (200 km paved) from the deep water port of Mtwara (**Figs. 3 and 4**).
- PGP prioritized the development of license PL10332 with strong ESG principles [3, 4] for the clean energy
- Ni-43-101 compliant estimate of 34.7 Mt of Indicated Resource and 62 Mt of Inferred Resource
- Ore ranges from 20.1 % to 5.45 % TGC (total graphite content), exceeds China @ 2-4 % TGC
- Traditional floatation techniques achieve concentrate of 95 %TGC (total graphitic carbon)
- Flake size: 20 % jumbo; 50 % large; 20 % medium, 10 % fine for diverse offtakers
- Phase 1 = 12,000 tpa concentrate while establishing parameters for full production (80,000 tpa concentrate)
- Pula has secured:
  - Lead investor, BVG, US-based VC firm
  - MoU for offtake w/ Singapore trading company
- Post-capital injection, Phase 1 complete in ~12-16 months. Phase 1: IRR 58 %, Payback period 25 months, Profitability Index 309 %
- The Pula Group Board includes:
  - Ambassador Charles Stith, former U.S. Ambassador to Tanzania
  - Dr. Mary Stith, Pula President
  - Dr. Kenneth Jennings, Yale-trained geologist
  - Mr. Bernard Katompa, former BHP Executive

physical data at 1 km line spacing and 120 m ground clearance. 16 percent of Tanzania has high resolution airborne geophysical data (200 to 250 m line spacing and ground clearance of 45 to 70 m). 19 percent of the entire country has geochemical data and there is increasing availability of centralized and standardized modern Database Management System.

Pula Group's new ethical Model for sourcing critical Minerals from Africa

Along with the high caliber of its Tanzanian graphite opportunity, The Pula Group, an US-based company, is setting high ethical standards in the mining sector. The Group's subsidiary for developing the project is Pula Graphite Partners (PGP), a 50-50 joint venture with local strategic partners. During the exploration phase, PGP already has a superior track record of corporate social responsibility. It has developed an approach to respond to the immediate, mid, and long-term needs of communities in it operates. The Pula Approach is geared to ensure that communities benefit from its projects throughout the life-of-mine.

Using 'First Pit, First Plant' approach, the mine can be scaled up with ease to the full capacity of 80,000 t/a. This adaptive approach to mining helps mitigate environmental as well as economic risks and the 'too big to fail' attitude that has sunk many large-scale mining projects.

The viability of the PGP graphite opportunity in Tanzania rests on its social license to operate. The U.S. and EU have designated graphite as a strategic mineral that is critical to their respective economies and security. PGP aims to develop a new mining model for Africa that links global demand, local beneficiation, and national development.

Minerals that aid the greening of the economy, such as graphite, are opportunities to create a more sustainable and ethical mining sector and global future. In that respect, Tanzania is a critical player. Its mineral wealth and development needs require new standards of resource extraction, which can be provided by innovative, adaptive, and ethical companies such as the Pula Group [3, 4]. As Germany looks to develop alternative energy supply chains that don't leave it dependent on conflict riddled regions of the world, Tanzania provides a viable option.

The Pula Group is working together with Tanzanians to lead North-South collaborations charge from East Africa to ensure that Africa and the world achieve the development goals of the clean energy transition simultaneously.

Conclusion

Tanzania and the Pula Group offer interesting opportunities for cooperation in the mining sector. The essential data are summarized in the **Infobox**. For further information the Pula Group is at your disposal.

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Mine Water as a Resource for Critical Raw Materials in Germany

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The new IAW3³ research project being carried out by the Research Center of Post-Mining at TH Georg Agricola University of Applied Sciences (THGA) is looking at the possibilities for extracting critical and valuable resources from mine water and its precipitates. This involves taking samples at a number of RAG water pumping stations in the German Ruhr, Saar and Ibbenbüren areas in order to draw a comparison between the constituents of mine water and those substances that have been deemed as critical by the European Commission [1, 2]. The research will also examine whether and how the target elements detected in the slurries of the precipitates and preparation plant residues are able to accumulate by way of various co-precipitation processes. This project therefore constitutes an important step towards strengthening resource independence from third countries and will also do much in helping mine water to be seen as a 'reusable material'.

Mining • Post-mining • Mine water • Raw materials • Raw materials security • Research

The mutual global reliance on commodities and strategic resources has recently and repeatedly been brought into the public spotlight not just by the dwindling supply of resources but also by a number of concurrent global crises. Back in 2011 the European Commission published a list of 14 critical resources. This was expanded to 20 in 2014, to 27 in 2017 and finally, in September 2020, to 30 (**Fig. 1**) [1]. Many of these materials are fundamental to today's technologies (**Table 1**), particularly some of the alkaline metals and alkaline earth metals, the transition metals and lanthanides (rare earth elements), and the metals of the third to fifth main group. **Table 1** presents a selection of metal resources (arranged according to atomic number) along with their potential applications and supply dependence on third countries outside the EU.

Many of these raw materials present an import dependence of as much as 100 %, though this relates to the EU as a whole. Spain, for example, supplies 100 % of the strontium within the EU, which looked at the opposite way means that the other countries, including Germany, no longer have a strontium production industry of their own. One of the aims of the European Union is to reduce the level of dependence on imports from third countries and to develop new procurement bases within the borders of the EU. And the mine water contained in the former Ruhr, Saar and Ibbenbüren coalfields may constitute a new source of supply for materials of this kind.

The IAW3³ Research Project

The research project in question, namely 'Innovative processing technologies and their potential for material recovery from mine water, precipitates and processing residues from the Ruhr, Saar and Ibbenbüren coalfields with a particular focus on critical metal resources (IAW3³)', which is being funded by the RAG Stiftung (RAG Foundation), will sound out how mine water can make a valuable contribution to resource security. It is being predicted that when the mine-water pumping scheme is fully up and running the former Ruhr coalfield will be producing some 95 mill. m^3 of mine water a year on a long-term basis [3]. Much of this water is already exhibiting a high level of mineralisation along with increased concentrations of critical elements whose chemical quality has already been analysed as part of the standard mine-water testing process. However, for the purpose of potential raw materials extraction these mine-water analysis procedures have to adopt a different focus. The aim of the research project is to detect relevant elements in the mine water and to assess their material loads before proceeding to examine the valorisation potential as a function of the respective ele-

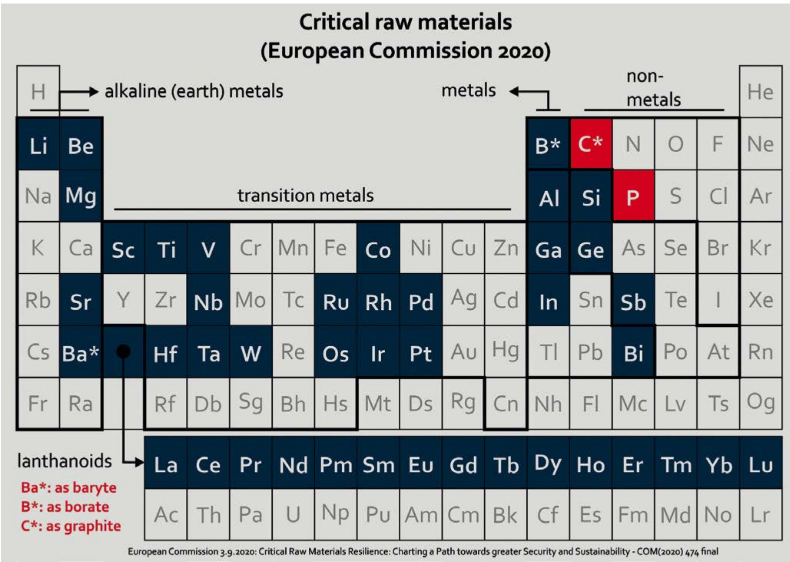

Fig. 1: Critical raw materials according to the European Commission 2020 [2]
Blue fields metals and semimetals; red fields non-metals; excl. energy resources, and some listed minerals.

ments. This work will not only focus attention on those raw materials that the European Commission has identified as critical but will also consider those elements in the broadest sense that have high realisable prices, the aim being to establish an economically sound basis for a raw materials extraction operation. The project will also set out to answer the question of how elements that are only present in the mine water in very small concentrations are able to accumulate in the precipitates and in the resulting ochre sludge: if the mine water rises up to the surface and then comes into contact with atmospheric oxygen, or if the pH value of the water is raised in some way, the dissolved ferrous ions will often be precipitated (**Fig. 2**). This can result in the co-precipitation of other metal species such as rare earths, which by this means can accumulate in the emerging slurries. If no slurries of this kind are available at the individual sites being investigated they can be produced by means of small precipitation reactors (injection of oxygen and/or alkaline material in order to raise the pH values) and sedimentation tanks.

Table 1: Selection of metal resources (according to atomic number), potential applications and supply dependence on third countries outside the EU

Element/ group	Application	Import dependence [%]
Lithium	batteries, alloys/metallurgy	100
Magnesium	light alloys for the automobile industry	100
Silicon	semiconductors, photovoltaics	63
Scandium	alloys, fuel cells	100
Titanium	alloys for the aerospace industry	100
Vanadium	alloys for the aerospace industry, catalytic converters	n.a
Cobalt	batteries, high-performance alloys	86
Germanium	coating of optic fibres, satellite solar cells	31
Strontium	ceramic magnets, alloys	0
Platinum group metals	fuel cells, electronics, catalytic converters	100
Tantalum	capacitors, super-alloys	99
Rare earth elements	permanent magnets (wind power), catalytic converters	100

Fig. 2: Strongly iron-contaminated mine water from the Dickenberg drift that is used to drain the now-abandoned western working panels of Ibbenbüren colliery. The precipitates are clearly visible as sedimented sludge in the bottom of the test tube.

The Status quo of Mine-water Analysis and preliminary Assessments

Over the years the mine-water analyses that have been carried out on a regular basis have always been aimed at assessing hydrochemical quality. While these long-running tests have therefore had a completely different objective in mind, nevertheless there is at least occasionally some concurrence between the elements being tested and the list of critical resources under discussion. These standard analyses were generally directed at boron, strontium, barium and, occasionally, cobalt. However, most of the 'critical' transition metals, including the rare earth elements and metals of the third to fifth main group, are subject to analytical omissions and it is hoped that this research project can fill in the missing gaps.

A number of rough assessments based on previously analysed elements suggest that the mine water does indeed have promising potential. The element strontium is particularly worthy of note here. This critical raw material has a high market price of over 13,000 €/t (at 99 % purity, as of October 2022 [4]). The high strontium concentrations present in the Ruhr and Ibbenbüren areas have also been apparent in the strontianite deposits of Münsterland [5], where as much as 7,000 t/a were being extracted at the end of the 19th century [6]. With mine-water concentrations of over 50 mg/l being measured at the Lohberg pumping station it is likely that the entire Ruhr coalfield area will have a material load of over 1,900 t/a with a theoretical value of more than € 25 mill. Further values that were calculated between 2016 and 2019 on the basis of average material loads and chemical analyses can be found in **Table 2**.

It should be noted in this respect that the calculations were based on metals with a high degree of purity, this requiring some elaborate, and therefore expensive, refining and processing. These calculations should therefore only be seen as a reference point for an indicative evaluation of the theoretical potential. Another question that has to be addressed is the degree to which the target elements can be precipitated from the water and accumulated in the resulting slurry so as to markedly increase the cost effectiveness of the extraction process or indeed to make it viable in the first place.

International Experience: Accumulation of Rare Earth Elements in Slurries

Investigations into the theoretical potential of mine water as a source of critical raw materials have been under way at international level for a number of years [8]. In Portugal, for example, a research team has been looking into the accumulation of rare earths at various points associated with a passive mine-water processing plant [9]. They found that as much as 185 mg of neodymium and nearly 300 mg of cerium can be accumulated per kilogram of slurry. The sum total of all the rare earths investigated was found to exceed a concentration level of 700 mg/kg slurry, while the original concentration of these elements in water was only in the tenths of micrograms.

Promising work has also been under way in the former coalfields of the Appalachian Mountains in the USA [10, 11, 12]. Because of their importance for the nation's economy and defence industry these investigations are also being funded by the US Department of Defense. The project found that 46 % of the investigated sites contained a concentration of more than 300 mg of rare earths per kilogram of slurry and that 31 % of all the locations tested exhibited over 1,000 mg per kilogram. It has been established that the concentration levels of rare earths in the precipitation products of former coal mines in the Appalachians generally exceed the original concentrations in the mine water by a factor of some 2,500 (**Fig. 3**). This means that in total something over 700 t of rare earth elements must have accumulated in the slurries that have yet to be deposited. The yield from mining slurries should in future exceed 1,000 t/a with an estimated value of US-$ 245 mill. [11].

All told, there is a wide variety of benefits to be gained by extracting rare earths from mine water or from the slurries that are produced at processing plants and many of these can logically also be applied to other raw materials and metals [11, 12, 13]:

- There are no significant radioactive by-products associated with the extraction of rare earths from mine water, compared for example to the conventional methods used for producing uranium and thorium, to name but two.
- The production costs are moderate, as the starting material (precipitation products/slurries) has already accrued.
- There is no requirement to construct a new (underground) mine, a fact that can improve public acceptance of the scheme.
- The concentration levels of rare earth elements in mining slurries have in some cases been found to exceed that obtained using conventional extraction methods based on typical source rock.

Table 2: Theoretical values for the material loads of selected elements in the mine water of former mine workings in the Ruhr, Saar and Ibbenbüren coalfields as based on average concentration levels measured between 2016 and 2019

Data: RAG AG; raw material prices according to [4] and [7]

Element Purity	Manganese > 99,7 % (electrol.)	Cobalt > 99,8 % (electrol.)	Nickel > 99,8 %	Copper Grade A	Zinc > 99,995 %	Strontium 99 %
€ /tonne	4.221 €	69.094 €	22.646 €	5.981 €	3.123 €	13.515 €
Ruhr::	149.000 €	n.a.	43.000 €	15.000 €	48.000 €	26.300.000 €
Ibbenbüren:	283.000 €	308.000 €	26.000 €	1.500 €	22.000 €	2.500.000 €
Saar:	52.000 €	n.a.	148.000 €	66.000 €	252.000 €	334.000 €

n. a.: no data available
electrol.: electrolytic, suitable for use as a cathode material in energy storage systems.

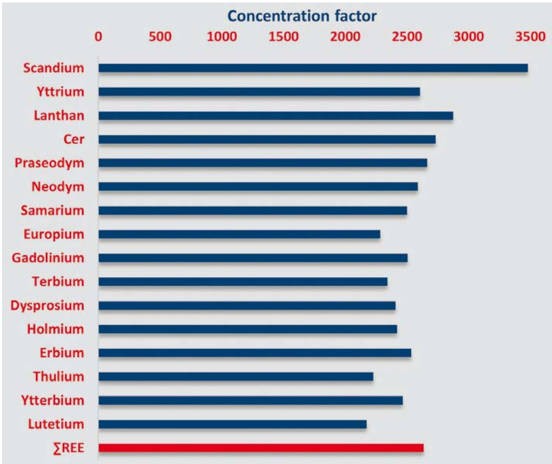

Fig. 3: Typical concentration factors of rare earth elements (plus scandium und yttrium) in the precipitates of mine water from the former coal mines of the Appalachian Mountains [12]

- The reduction of potential pollutants and their partial valorisation can reduce the cost of the mine-water processing operation.
- New jobs can be created and this can have a positive impact on structural change in the local area.
- There is a reduced reliance on rare earth elements sourced from third countries.

The last of these – the reduced dependence on third countries for the supply of certain elements and metals – is a benefit of enormous importance in times of international crisis when there is a shortage of raw material supplies from many countries.

Concentration Development and the 'First Flush'

Although one of the frequently named benefits of extracting raw materials from mine water is the automatic, long-term and sustained replenishment of dissolved ions [11, 13], it cannot be assumed that this will apply unreservedly to all mines. The term 'first flush' was coined

Special Topic

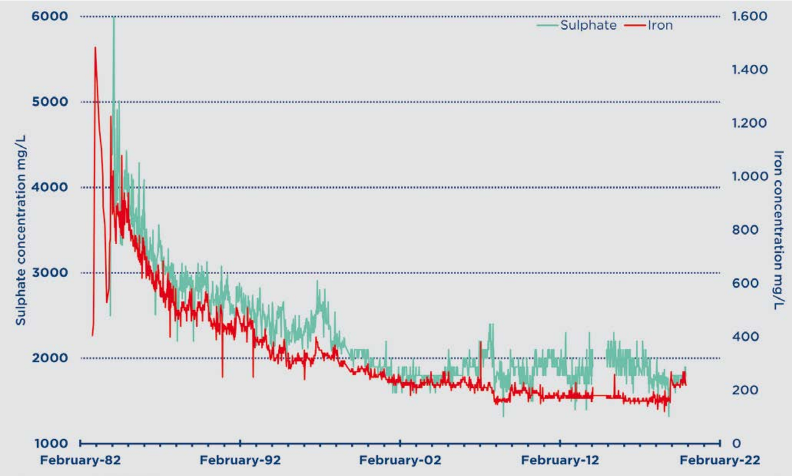

Fig. 4: Example of a 'first flush': development of the measured iron and sulphate concentration in the discharge from the Ibbenbüren western district via the Dickenberg drift
Data: RAG AG

by PAUL L. YOUNGER[14] in 1997. Subsequently translated into German by WOLKERSDORFER [15] as the 'preliminary flushing effect' (Erstspülungseffekt) this describes the initial increase in the overall mineral content of a body of mine water following a general upward movement in the mine-water level and the subsequent and gradual decrease in mineralisation. According to the empirical database this decline in the concentration development of all the dissolved ions more or less corresponds to four times the length of time that the rise in mine water would have taken to achieve a hydraulic balance above the worked-out deposits. From this moment on the dissolved ion concentrations broadly correspond to the geological background level. This development can be attributed to the secondary minerals that were produced during the coal winning phase [16, 17]. The latter are formed from the decomposition products of disulphide (e.g. pyrite), are highly soluble in water and can rapidly be flushed out. In the event of flooding and the deprivation of atmospheric oxygen the disulphide weathering comes to an end, as does any new genesis of secondary minerals.

At the Ibbenbüren mine site, where the mine water is to be drained off via a new underground tunnel (the 'mine water drain') that will run above the former working levels, a gradual reduction in the mine-water mineralisation level is therefore to be expected. Similarly this could also be observed in the Westfeld (western) district of the Ibbenbüren workings that was abandoned some forty years earlier and where both the measured sulphate and the iron concentrations – as being representative of overall mineralisation levels – significantly declined over time (**Fig. 4**). Comparable developments are expected in conjunction with the mine-water drainage plan being proposed for the Saar coalfield [18].

However the situation is different in the former Ruhr coalfield, where the long-term plan is to maintain a safety margin between the mine water and the drinking-water reserves in the overlying rock and therefore also to ensure that parts of the former mine workings are not flooded with water [19]. This means that disulphide weathering under the genesis of new secondary minerals can continue to occur in these water-free areas, this resulting in the sustained release of these mineral phases. Under these underlying conditions the kind of sharp decline in the overall mineralisation of the extracted mine water that was witnessed in the western districts of Ibbenbüren mine, and which will in future also be observed in the eastern section too, is unlikely to be repeated in the Ruhr coalfield area.

Summary and Outlook

The recovery of critical and valuable metals from mine-water precipitates and slurries is strategy of great future potential. One of its greatest benefits is that it will reduce reliance on raw material supplies from third countries. In addition to this, projects of this kind can at the very least mitigate the costs incurred for the mine-water processing stage that is often required in such cases. In order to examine the feasibility of such an operation in the former coal-mining regions of the Ruhr, Saar and Ibbenbüren a new research project (named IAW3[3]), which is being funded by the RAG Stiftung, will seek to determine a number of potential target elements now designated as critical and valuable resources. To this end samples of mine water and precipitates or slurries will undergo a broad-based screening exercise and will be assessed as to their suitability for possible processing. If necessary, small precipitation reactors will be set up at the different pumping sites in order to generate precipitates for further analysis. Extensive research and analysis of international experience with new methods for the valorisation of mine water and processing residues [20] should result in innovative options for a sustainable and cost-effective approach to mine water as a valuable resource, such processes being adapted to meet local conditions and circumstances. Mine water was for many years seen as a waste product that had to be disposed of at great cost: the time has now come to exploit this highly promising source of raw materials and to take full advantage of all the benefits it has to offer. The new research project will also seek to examine the extent to which hyperspectral sensors can provide added value both for the monitoring of mine-water discharges and for the prospection of possible raw material sources [21, 22].

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Further Information on the Research Centre Post-Mining

In order to confront the challenges arising from the many different issues associated with the post-mining environment the Research Centre of Post-Mining has gathered together a team of experts from a wide range of scientific fields who regularly engage in the interdisciplinary exchange of knowledge and ideas. Further information on current research work under way at the Research Centre can be found on the department's website. This also contains a number of final reports that have been published as part of the new magazine series 'Reports on Post-mining' and which interested readers can download for free.
www.nachbergbau.org

Special Topic

Special Topic

Webinar on Tailings & Co. – The raw Materials Potential of Mining Spoil Heaps and Waste Storage Sites

In November 2022 EE Energy held their fifth webinar on mine tailings under the direction of Peter von Hartlieb.

Presentations included the work of the Research Centre of Post-Mining at TH Georg Agricola University of Applied Sciences in Bochum and projects such as the RAG-sponsored study of resource extraction and critical raw materials from mine water and the geomonitoring of tailings dams.

Supply Chains and Resource Dependence

The crisis situation currently affecting the entire world shows how a reliance on certain goods and critical resources from third countries can pose a serious threat to the domestic economy. There are now calls for the sustainable extraction and utilisation of these resources to be made a priority issue and this has shifted the focus back to indigenous raw material resources.

Energy-transition Resources in NRW

As the paper by Reker et al. shows (pages 33 to 38 in this issue of the GeoResources Journal) mine water from the former collieries in the Ruhr, Saar and Aachen coalfields as well as from Ibbenbüren mine has real potential to offer. It contains various minerals in dissolved form that have to be continuously monitored in order to ensure that any environmental burden resulting from discharges into receiving water courses is kept within acceptable limits. Experiences from tests on rare earths and other valuable minerals have indicated that the mine water that has built up in the former coalfields may in some cases contain appreciable quantities of resources. The aim of the THGA's $IAW3^3$ research project is to analyse this water with a view to the cost-efficient recovery of critical metal resources and to assess its potential as an ecologically sustainable source of raw materials.

Sensors for NRW geo- and environmental Monitoring Services – looking at Things close-up!

Some 57 tailings dams around the world suffered catastrophic collapses between 2000 and 2020. Tailings are mining residues that are traditionally stored in artificial lagoons or slurry ponds. About 60 % of these incidents occurred in Europe and Asia, while the remaining 40 % took place in North and in South America. Mine tailings represent a challenge for both science and industry. What is needed in this area is better technology for merging and matching the differently sized 'magnifier systems'. Satellite-supported sensors provide high-resolution chronological overviews, copter- and drone-supported sensors can produce high-resolution spatial images, while ground-mounted sensors provide the point measurements that are vital for the surveillance of tailings dams. All these data have to be evaluated and prepared for the relevant experts, and also for other interested parties in the public sphere. Modern geo- and environmental monitoring is therefore a valuable tool for shaping and engaging public opinion. More information on the THGA project can be found in:

Rudolph, T.; Goerke-Mallet, P. (2021): Increasing social acceptance in the management of tailings storage facilities (TSF). GeoResources Journal (3-2021), pp. 35–40. Online:
https://www.georesources.net/download/GeoResources-Zeitschrift-3-2021.pdf

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Practical Examples of Concrete Logistics in Shaft Sinking – a real Challenge for Transport and Handling Operations

Thomas Ahlbrecht, Redpath Deilmann GmbH, Dortmund, Germany

Like steel, concrete is a vital material for shaft construction work and is needed in practically every undertaking of this kind. This paper examines the special aspects associated with the use of concrete in shaft sinkings, this being dependent on the nature of the assignment and on the local conditions. Practical examples are given to illustrate and explain the techniques used for shaft restoration and repair, shaft deepening and new construction projects.

Mining • Shaft sinking • New construction • Repair • Concrete • Shaft deepening • Transport and handling

While the use of concrete as a building material is well known in the general construction and civil engineering sectors, its application in the field of mine shaft sinking is subject to a quite different set of conditions.

In building construction and civil engineering the worksite is usually close to the construction trench and so is easily accessible for mixer trucks, while the transport distances are fairly short and there is often a sufficient amount of space available around the deployment point. When it comes to shaft sinking, however, access to the construction area tends to be quite limited and any concreting points below ground are generally far away from the delivery site. The site logistics may therefore have to be set up for the operation of cranes and concrete pumps. Shaft construction projects almost always operate around the clock and the concrete therefore has to be prepared as and when it is required by the various working processes. However, the time slots for the concreting phases tend to be restricted to daytime hours through the week as economic considerations usually mean that they are linked to the opening times of the ready-mixed concrete plants. Concrete can of course be delivered outside these opening hours, but this level of service comes at a premium. All shaft construction work is therefore geared very precisely to the concreting phases on the basis of long lead times.

In the case of civil engineering projects it is usually possible to have easy access to every point around the construction site. While concreting is under way on the first floor, for example, plumbers and electricians are able to work in the basement (**Fig. 1**).

By comparison, the available working area at the shaft opening will generally be between 40 and 60 m², depending on the diameter of the excavation, though sometimes this can be even less than 10 m². The sinking floor, or in-shaft workplace, can only be reached by means of the hoisting system (sinking bucket) and there is usually only one of these available (**Fig. 2**). This installation has to transport both workers and materials,

Fig. 1: Structural engineering projects usually allow other work to be carried out while concreting is under way.

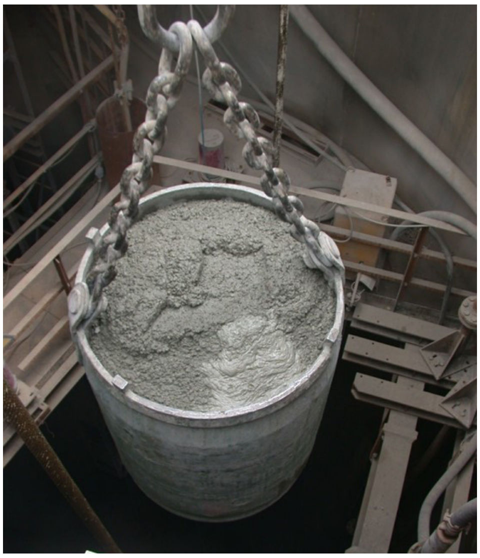

Fig. 2: The shaft sinking floor can generally only be reached by way of the sinking bucket.

Fig. 3: Cramped site conditions for the concrete formwork

Fig. 4: Delivering cast-in-situ concrete is a laborious process.

which therefore includes the concrete. Manoeuvring supplies in with a crane, or even with a concrete pump and boom system as is often used above ground, is simply not possible in shaft sinkings. The concrete mixer truck therefore cannot come within range of the placement point but has to park up near the shaft mouth and the concrete often has to be transloaded several times before it reaches its final destination. After it leaves the truck the material has to be transferred on 'somehow or other', depending on the particular installation conditions, and this 'somehow or other' has to be newly planned each time and then ultimately put into practice. While multi-deck working platforms naturally facilitate some degree of parallelisation of the different working processes, nevertheless some operations are mutually exclusive and cannot take place simultaneously.

The requirements laid down in the relevant standards for structural concrete take up an entire chapter in themselves and these do not make the concreting operation any easier, especially in shaft construction work. One of these requirements specifies that the concrete has to be placed within the formwork within 90 minutes of the initial mixing process. This presents a real challenge for mining work in general and for shaft sinking operations in particular. The individual aspects of this could fill an entire book, let alone one chapter.

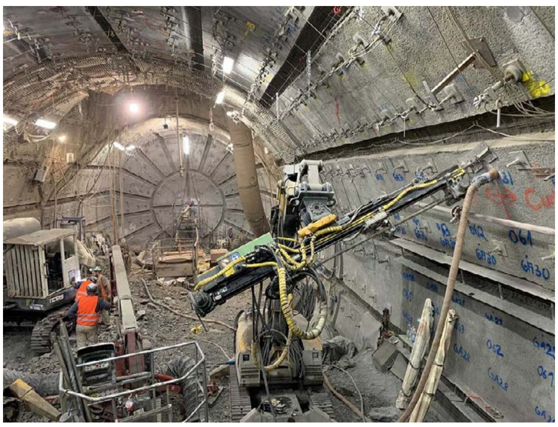

Fig. 5: One of the main advantages of shotcrete is flexible adaptation to the geometry of the spraying surface.

Concrete Placement

Cast-in-situ Concrete or Sprayed Concrete

Shaft construction operations use concrete either in the form of cast-in-situ concrete or as sprayed concrete (shotcrete). From a logistics point of view in-situ concrete and shotcrete call for quite different operating strategies and site facilities.

In the case of in-situ concrete the freshly mixed material is poured into place behind pre-set formwork and allowed to set hard. The formwork system has to be designed specifically for the confined space conditions (**Fig. 3**) and filling the shuttering space is often a cumbersome operation (**Fig. 4**). The concrete has to be applied to a minimum thickness as the reinforcement requires a sufficient concrete covering not only for structural reasons but also to ensure adequate corrosion protection. Pouring concrete as an overhead operation is a difficult process to carry out in a mine shaft or at an inset point.

Shotcreting involves the application of the concrete over a wide area. The material is delivered by compressed air through pipes or hoses and is 'fired' at high speed on to the placement point. The advantage of this method is that the concreting area is geometrically flexible and the shotcrete can also be readily applied overhead (**Fig. 5**). No shuttering is required. However dust and rebound can create problems for the shaft workers. The shotcrete is often reinforced with steel, stainless-steel or carbon fibre mats. If these are not to be used the reinforcement can be provided in the form of steel or synthetic fibres that are added at the mixing stage. Throughputs of between 1 and 15 m^3/h are possible, though when a hand-held nozzle is used the upper limit is usually in the region of 5 m^3/h. Higher spraying rates can be achieved by deploying a robotic shotcreting machine, or manipulator (**Fig. 6**).

Project Remits and relevant Constraints

Shaft construction work can involve a range of tasks that require completely different concrete properties and logistical methods:

- **New constructions**
- **Repair and renovation**
- **Abandoning of mines and shafts (not covered in this paper)**

Shaft construction, in other words the sinking of a new shaft, mainly involves drilling and blasting work. The placement of concrete is just part of the overall sinking cycle. The individual processes that make up this sequence of operations are depicted in **Fig. 7**. Each advance cycle is dominated by the drilling and firing sequence and then by the removal of the excavated material. Some of this work can be undertaken in parallel with the aid of working platforms (shaft stages). However there are limits to this as, for example, no persons are allowed to remain on the sinking floor when the support ring is being set up. This means that concreting and dirt clearance often cannot be carried out concurrently, as would be desirable. The three key working processes that make up a shaft sinking are interdependent and must be planned and organised as effectively as possible if maximum sinking performances are to be achieved.

Access to a mine shaft is rarely easy at ground level as there will always be a headgear structure right above the shaft along with other buildings around the shaft mouth. Damaged areas will usually be located deep into the shaft column and may often be hundreds of metres from the surface. The existing shaft winding installation will be set up to meet production needs or to provide manwinding and materials transport services. Repair work must therefore be aligned with the existing equipment and facilities and also has to take account of shaft fixtures such as brackets, winding components and infrastructure. The work is further complicated by the fact that colliery requirements must always take priority. As a result, repairs can usually only be undertaken over one or two shifts or must be done at weekends and during non-production periods. There is no point in complaining about this situation – it just has to be accepted.

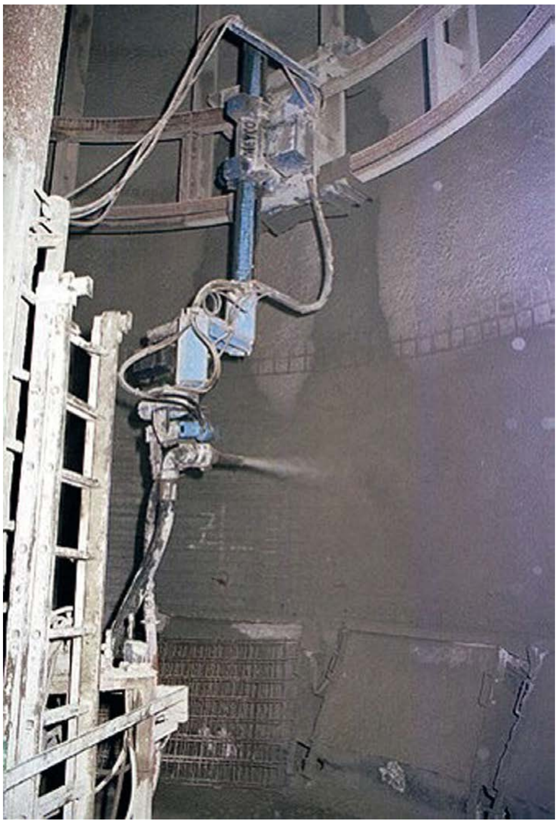

Fig. 6: Using a manipulator to apply shotcrete

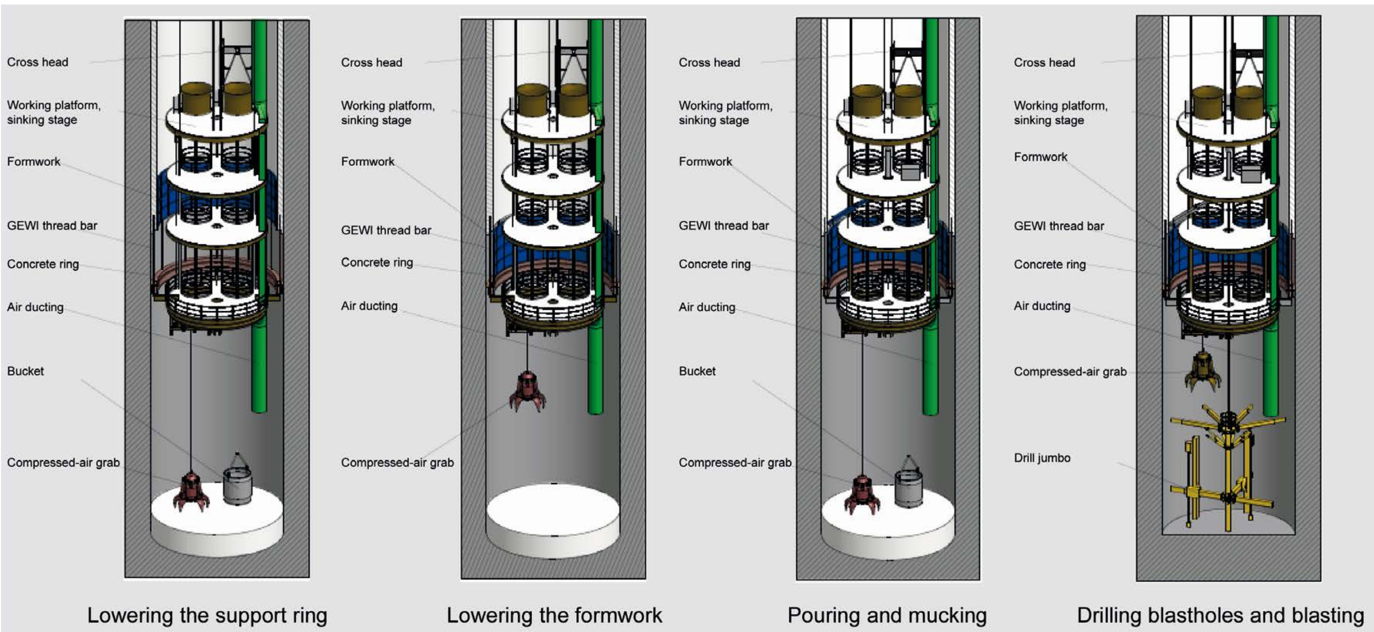

Fig. 7: Key phases in the working cycle of a new shaft excavation

Concrete Delivery Methods and Process Selection

Four options are available for supplying concrete to the shaft:

- Sacked delivery
- Big Bag delivery
- Silo-based delivery
- Mixer trucks

In-situ concrete is supplied to the shaft in transport buckets or by means of a slick line system. Both methods have their advantages and drawbacks, as described in detail in the practical example given below.

One technique used for shotcreting is the 'thin flow' process in which the supply pipe is not completely filled with concrete. This is the preferred method for dry concrete spraying and is rarely used for wet spraying. The other option is the 'dense flow' process in which the delivery pipe is almost always kept completely filled. This is normal method for wet spraying and is primarily used in conjunction with shotcrete manipulators.

Shotcrete is usually delivered downwards, though under special circumstances it can also be applied in an upwards direction. In the latter case placement heights of as much as 100 m can be achieved when using the dry spraying method. Pumping wet concrete in an upwards direction presents a significant challenge and is not always successful.

The required pumping rate is the decisive factor when it comes to choosing the most suitable method as all the individual components that make up the delivery system are measured against this. The specified concrete quality and the formulation needed to achieve this then come into play as part of the subsequent planning process.

Practical Example: Prosper No. 10 Shaft

Shaft Deepening

The operation to extend No. 10 Shaft at Prosper Colliery in Germany, though it was carried out quite a few years ago, nevertheless is a good example of the type of problems faced in projects of this type. The shaft, which measured 8 m in diameter and 1,027 m in depth, came into service at the end of 1979 and was constructed in order to access coal measures on mine level 6. The downcast shaft was already working to full capacity with manwinding and materials transport duties (**Fig. 8**).

The existing shaft was now to be extended by some 300 m to a depth of 1,350 m. The contract for the work was awarded to a shaft-extension consortium comprising Deilmann-Haniel (now Redpath-Deilmann) and Thyssen Schachtbau of Mülheim an der Ruhr. The deepening work was to be carried out without any interruption to normal winding operations. Another feature of the project was that the shaft did not exhibit a continuously vertical alignment owing to the influence of ongoing mine workings on one side.

Fig. 8: Prosper no. 10 shaft

A shaft safety platform was erected in the old shaft sump. This platform was designed as a steel structure in accordance with TAS (Technical Shaft Requirements) specifications [1] and included an 8 to 10 m-thick layer of lava gravel. The existing sump cavity was undercut in order to accommodate a winching chamber along with all the equipment needed for the shaft sinking operation.

The colliery's existing concrete transport equipment was not to be used for the shaft extension work. The in-situ concrete therefore had to be supplied through a free-hanging slick line from the surface mixing point to the formwork some 1,300 m below, this to be done without hampering the ongoing shaft operations. This meant installing an API materials supply pipe 65/8" in diameter (internal diameter approx. 150 mm) to a depth of about 1,000 m and extending this to keep pace with the shaft sinking work. The extensions were created using DN 150 mm PN 160 flange pipes.

Not every type of concrete is suitable for applications of this kind as the concrete formula has to be adapted to the vertical conveying process. This meant that the maximum grain size, the particle size distribution and the cement content all had to be carefully selected in order to prevent any segregation in the slick line and to ensure that the specified strength levels were achieved after placement.

The following key points had to be clarified in advance of the operation:

- Is there a continuous line-of-sight path available?
- Are there projecting edges present?
- Can the mixer truck gain direct access to the mouth of the slick line?
- How can the lubricant compound be disposed of?
- How can the cleaning water be disposed of?
- What kind of pipe system can be installed rapidly down to the upper level of the extension inset?
- How is the slick line to be connected to the working scaffold?

- What is to act as an impact absorber for the concrete as it reaches the scaffold?
- Is there a need for final mixing on the scaffold?
- How is the concrete to be distributed around the scaffold behind the shuttering?

A path for the slick line was found in the western zone of the shaft cross-section near the counterweight. This was also to act as a route for the supply of concrete from the mixer truck (**Fig. 9**). Four safety classes were defined, these relating in part to the shotcrete layer. The shotcrete was not delivered directly from the surface and through the slick line but was supplied dry bagged and then processed at the 'shaft extension inset' using a dry-mix spraying machine. This method proved to be fairly inefficient and created bottleneck problems for the sinking operation. However the system could not be changed within the operating phase and so it was retained until this section had been completed.

As it arrived inside the working platform the concrete was transferred via a hose line from the slick line to a secondary mixer set up on deck 2. The mixing system was also fitted with an impact absorber to cushion the effect of the incoming concrete. After mixing the concrete was delivered to a distributor with three discharge hoses. These were directed into the area behind the shuttering and could pump the concrete into the outer perimeter of the shaft (**Fig. 10**).

Construction of new Landing on Mine Level 7

The construction of the new shaft landing on mine level 7 imposed further demands on the concrete logistics system.

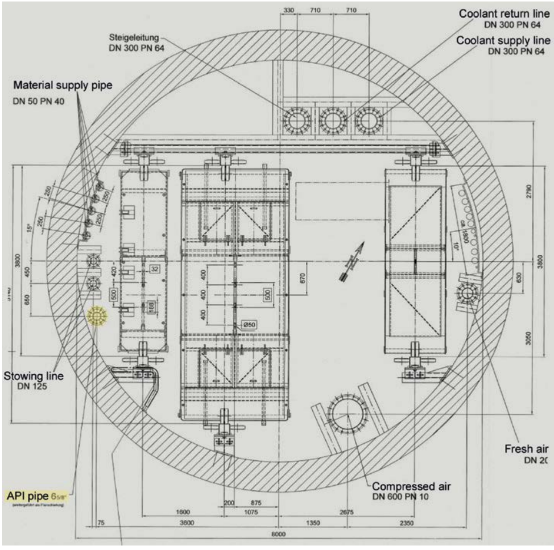

Fig. 9: Shaft cross-section with API slick line

Grouted anchor bolts and dry-sprayed shotcrete were used for the outer shell in this area so that the landing could be created section by section (**Fig. 11**). The relatively small quantities of material required meant that concrete could be supplied in bags to the placement point.

The inner shell was created using a different technique in that wet-spray shotcrete was supplied directly from the surface and applied by means of a manipulator. The shotcrete layer varied in thickness from 0.4 to 0.7 m and was installed in conjunction with a system of lattice girders. As the specification called for a compressive strength of at least 40 N/mm² the shotcrete was pre-mixed with steel fibres.

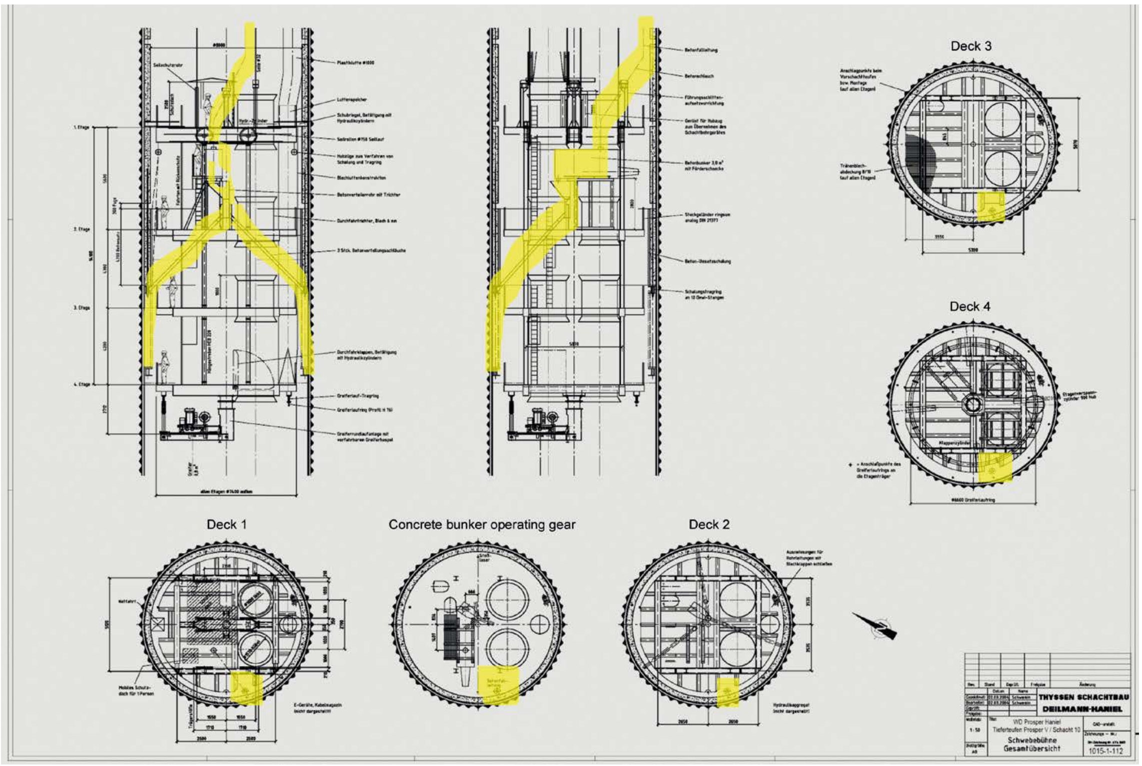

Fig. 10: A hose line on the shaft scaffold transfers the concrete from the slick line to a secondary mixer on deck 2.

Fig. 11: Excavating the shaft landing on level 7 – external support system with grouted anchor bolts and dry-sprayed shotcrete

The working scaffold was positioned above the shaft landing where the concrete was received from the slick line and transferred to the secondary mixer. The material was then further processed using a concrete piston pump with a dosing system for the steel fibres and liquid accelerator. The accelerator medium had to be dispensed in such a way as to neutralise the effect of the retarder that was added at the concrete plant to allow for the delivery time. Several weeks of familiarisation were needed before the entire supply chain worked efficiently.

Project Facts and Figures

- Installation of approx. 1,000 m of API pipe, March 2005
- Average of 68 m^3 of concrete processed for each 4.2 m of shuttering
- 6.3 h required for moving and re-setting the formwork
- 5.5 h required for the concreting phase, i.e. about 12 h in total
- Gross delivery capacity (incl. setting up and dismantling) 12.4 m^3/h

Fig. 12: Shaft No. 1 at the Zielitz potash mine

- Net delivery capacity (excl. set-up and dismantling) 17.0 m^3/h, this corresponding to roughly two mixer trucks of 9 m^3 payload per hour
- Concrete delivery rate for sinking phase approx. 2,800 m^3
- Wet-spray concrete additionally required for inner shell of landing on level 7
- Extensive preparations and tests required for complex logistics when wet spraying with steel fibres in shaft landing area; wet spraying operations proved difficult to realise
- All specified concrete qualities were met
- No blockages in the shaft pipe and no wear recorded

Sadly, Prosper-Haniel colliery – Germany's last productive coal mine – was closed in 2018 and the shaft was subsequently filled-in.

Practical Example: Renovation of Zielitz Number 1 Shaft

Shaft Number 1 at the Zielitz potash mine in Saxony-Anhalt, which is Germany's most productive winding shaft, was originally sunk in the late 1960s (**Fig. 12**). The key features of the shaft and its integral winding installation are as follows:

- Winding shaft producing 40,000 t/d, downcast
- Diameter 7.50 m
- Depth 810 m
- Tower-mounted headgear with 9 MW Koepe winder
- Rope-guided skip installation with 50 t payload
- 8 headropes, 8 guide ropes, 3 balance ropes
- Supports
  - Tubbing segments from ground level to a depth of 475 m
  - Brickwork lining below this level
  - Compound tubbing from 495m to 515 m depth
  - Brickwork below this
- 2017: the shaft is affected by convergence with some scaling damage
- Schachtbau Nordhausen (SBN) carries out initial stabilisation work
- 2018: SBN assembles skip and scaffold system
- the working scaffold is set up in about 16 h
- 2018–2023: DH/TS consortium carries our repairs in six tranches at a depth of between 538 and 565 m.

The damaged area is located at a depth of 538 to 565 m and has created an ovalised shaft cross-section (or 'cherrystone effect') in the main east-west axis of principal stress. The workplace for the repair of the supports in Zielitz Number 1 Shaft is sited in the central shaft zone about 550 m below ground level and some 150 m above the bottom landing. The renovation concept called for the use of injection bolts of different length and a supporting layer of shotcrete (**Fig. 13**).

Number 1 Shaft at Zielitz mine, which operates on a continuous, around-the-clock basis, is essentially only used for raw salt production. Shaft renovation work can therefore only be carried out during the short summer breaks of about three weeks. The concrete is applied in the form of shotcrete. All in-shaft work is undertaken using a hoist and scaffold installation that has to be assembled at the start of the operation and then dismantled at the end of the production stoppage period (**Fig. 14**).

A wet-spraying operation was commenced in the summer of 2021 with the material being ejected upwards to the workplace. The concept used was as follows:

- Wet-spray process without fibres
- Vertical upwards pumping over a distance of about 160 m
- Using dry material of 0 to 4 mm grain size
- Pre-spraying of the shaft wall to a depth of 3 to 5 cm
- Inclusion of carbon-fibre mats of 51 × 51 mm mesh size with 6 mm diameter bars
- Spraying of the mats with a 5 cm-thick surface layer
- Total volume of shotcrete applied – approx. 100 m^3
- End result: a lot of effort for a small amount

The technology used in this case was deficient in a number of ways and could not be successfully applied. The concrete was mixed at the bottom shaft landing using dry material supplied in Big Bags. The conditions on the landing and the technology being deployed can be summed up as follows:

- The workspace was low in height, narrow and confined
- Excessive crisscrossing with mutual interference
- Too much lag time between mixing and final spraying (around 4 to 5 h)
- A very slow and tedious process
- Potential for changes in consistency

The concrete delivery pipe was of the heavy-duty type (DN 125) with a pressure rating of PN 160. The results did not live up to requirements and the concreting operation was therefore discontinued (**Fig. 15**). A subsequent review identified the sources of the problem as follows:

- Very complicated set-up
- Some separation of the mix when pumping upwards
- Components proved difficult to coordinate due to different levels of performance
- No time to complete a learning curve
- A confusing situation for upwards pumping
- Erratic water supply to the landing
- Lack of space in the landing area
- Continuous mixer achieves inaccurate mixing results
- Rinsing and flushing very time-consuming and can take 8 to 10 h
- Disposal of sludge and rinsing water is a laborious process, no disposal facilities on the scaffold
- Fresh water supply to the scaffold only possible by sinking bucket
- Wrong type of spraying equipment used
- Specified quality could not be achieved.

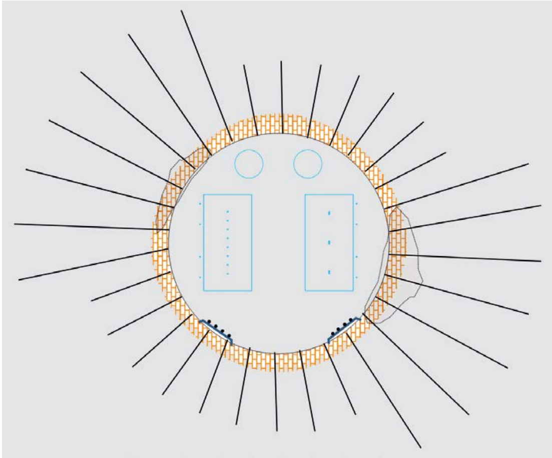

Fig. 13: Shaft cross-section with shotcrete shell and injection bolts of different length

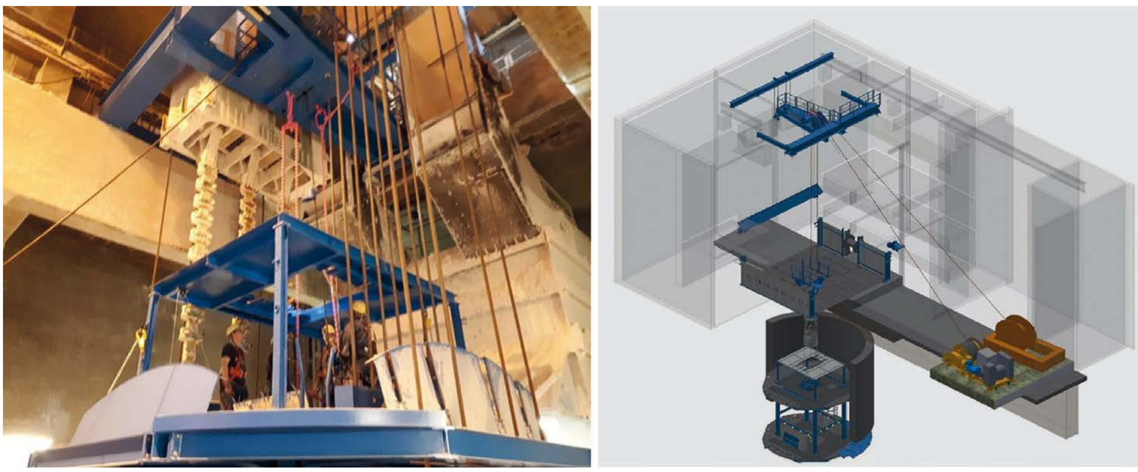

Fig. 14: Hoist and scaffold installation that has to be assembled and dismantled to coincide with each production stoppage

Fig. 15: Cramped shaft conditions (left) and the final result of the concreting operation (right)

It was therefore concluded that the operation could no longer be continued in this way and that a fundamental change was needed to the technical equipment. This decision had to be taken on the basis of the following project objectives:

- The repair and renovation work had to be fully completed in the 2022-2023 period
- An analysis to be carried out by the consortium (in-house) in conjunction with K+S and DMT Leipzig

The following possible solutions were investigated:

- Cast-in-situ concrete with industry-grade shuttering formwork
- Cast-in-situ concrete with liner plates
- Dry sprying
- Optimisation of the wet spraying process
- No more upwards pumping of wet concrete, if possible
- The equipment to be as simple and as manageable as possible.

The investigations and analyses led to the decision that the renovation work should be continued under the following conditions using dry spraying with material being supplied in Big Bags delivered from the surface:

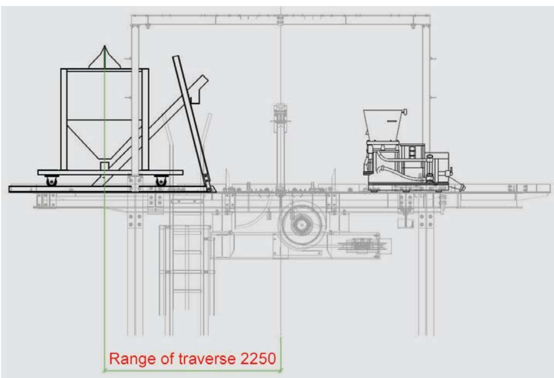

Fig. 16: Big Bag unloading process – parked position during the bucket transfer phase

- Buffer silo and spraying machine set up on the travelling scaffold
- Extensive testing of shotcrete from different manufacturers
- Tests on the technical equipment and spray nozzles
- Preliminary testing of all components and final run-through of the entire operation
- The sure provision of a steady water supply.

Once the final decision had been reached all items of equipment were tested, various materials were subjected to spray tests and drill cores were taken in order to determine the solutions likely to yield the best results. The Big Bags would now be emptied into an intermediate bunker set up on the shaft scaffold. This bunker would be designed to traverse across the scaffold so that the material could be transferred to the lower deck (**Fig. 16**).

The production stoppage for 2022 has now come to an end and the new system has been operating as planned. The shotcrete quality has been excellent and the repair work has now been completed on a longer section than planned. It seems that what went wrong in 2021 has now been very much put right in 2022.

Practical Example: Shaft Sinkings for a new Potash Mine in Belarus

The client Slavkaliy IOOO is building a completely new potash mine in Belarus [2] (**Fig. 17**). The scope of the work to be carried out by the contractors Redpath Deilmann was as follows:

- No. 1 shaft: production shaft to be sunk to a depth of 750 m
- No. 2 shaft: manwinding and materials shaft to be sunk to a depth of 700 m
- Internal shaft diameter 8.0 m
- Sinking to be carried out using a Herrenknecht Shaft Boring Roadheader (SBR)
- Overburden is water-bearing to a depth of 150 m
- Freeze shaft to extend to a depth of 165 m
- Cast-iron tubbing rings to a depth of 320 m
- Rock salt formations and potash seams present below 450 m
- The contract specifies an average sinking rate of 3 m/d.

The construction of two new mine shafts on a greenfield site in Belarus presented a quite different set of conditions from those that existed in the other projects described here, namely:

- The site was in open countryside with no existing logistics for transporting concrete
- Freeze shaft sinking
- Mechanised excavation technique with a high daily performance target.

Process Selection

- Dedicated concrete mixing plant to be set up with laboratory etc.
- No slick line, as this would present problems due to the minus temperature levels in freeze shafts
- The SBR suction system is sensitive to slurry so it is vital to reduce the consumption of process water to zero if possible. Distributing the concrete in the shaft as was done in the case of the Prosper shaft would have meant raising the SBR by a few metres and so for this reason a bucket delivery system was used. This allowed a greater leeway in the concrete composition for support work and for backfilling the tubbing rings.
- The SBR has an intermediate concrete tank that can be pivoted about 360°.
- Development of a new type of concrete bucket with remote-controlled emptying, this being required mainly to provide access when discharging at the SBR on deck 5
- The buckets require careful servicing and maintenance in order to maintain functional integrity
- A concrete pump and swivelling boom delivery system to be set up at the surface to load the buckets on the safety platform

A separate concrete plant was set up for both shafts so that concreting could continue around the clock. The material was to be delivered to the placement point by bucket. The logistics situation inside the SBR comprised various pieces of equipment designed for cutting and loading-out the debris. The 5 m-high formwork was used in its normal upper position. Every so often the shuttering had to be reduced to a height of 3 m and deployed as low as possible in its 'bottom' position in the extraction chamber so that the support system could be installed more quickly. Concrete placement was provided by a 360°-pivoting concrete distributor installed on deck 5. This machine had a 4.5 m^3 payload and was interlocked with the delivery system (**Fig. 18**).

The concrete was transported in buckets of 4 m^3 capacity. These were constructed in line with TAS specifications and were no longer to be discharged manually but would be operated electrohydraulically by remote control using battery power (**Fig. 19**). The buckets were loaded above ground using a concrete pump and pipe system with a swivelling boom that allowed the buckets to be filled on the safety platform.

Experience acquired during the Shaft Sinking and Support Operation

The freeze wall created for the freeze shaft sinking proved to be very stable (**Fig. 20**). The newly developed support ring proved easy and effective to use and contributed to a significant reduction in the formwork repositioning times. In the calcareous formations, where the shaft zone was not completely frozen through, difficulties arose as a result of significant agglutination in the suction system and in the buckets. This problem was only resolved with great difficulty (**Fig. 21**).

The shaft wall below the freeze zone became deconsolidated within a short space of time and began to crumble away. In March 2019 a collapse occurred within the shaft and the only remedy was to fill the resulting cavity with concrete (**Fig. 22**). After much consideration as regards the further course of action it was decided that the formwork should be reduced in height and brought as close as possible to the shaft floor (**Fig. 23**). This created a new set of operating conditions for the concreting work but did contribute to the ongoing success of the sinking operation.

The most important experiences gained from this practical example can be summed up as follows:

- A dedicated concrete plant is essential for supplying a non-stop construction site.
- Bucket delivery has proved to be efficient.
- The new type of bucket has been trouble-free and reliable.

Fig. 17: Slavkaliy IOOO is constructing a completely new potash mine

Fig. 18: View of shaft before the scaffold is lowered into place – the concrete distributor is in the left foreground

Fig. 19: Concrete bucket with electrohydraulic operation by remote control

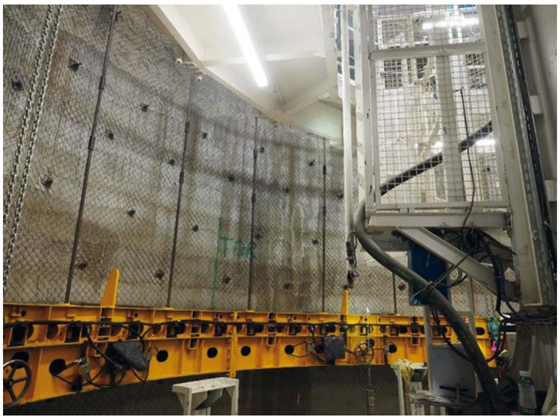

Fig. 20: Freeze shaft showing the very stable freeze wall

Fig. 21: Significant agglutination problem in the calcareous formations mainly affected the suction system.

Fig. 22: Collapse directly below the formwork support ring

- Bucket loading above ground is a feasible solution
- Concrete distribution within the SBR has been practical and problem-free.
- The formwork has proved flexible in use.
- The system can deliver six buckets an hour on average, i. e. about 24 m^3/h of concrete.
- With the shaft boring machine achieving advance rates of up to 7 m/d any hold-ups will generally be attributable to the concreting phase as the concrete requires a setting time of about 8 h until the formwork is stripped.

Conclusions

Operating conditions in the shaft construction sector tend to vary from project to project, with the result that the challenges arising usually call for an individual approach to be taken to the concreting operations, no general off-the-shelf solutions being applicable. Developing and defining the kind of solutions required calls for a well-founded body of experience on the part of the contracting company.

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This paper is based on a presentation delivered at the 10th Colloquium 'Fördertechnik im Bergbau' that was organised by the Institute of Mining at Clausthal University of Technology on 26th and 27th April 2022.

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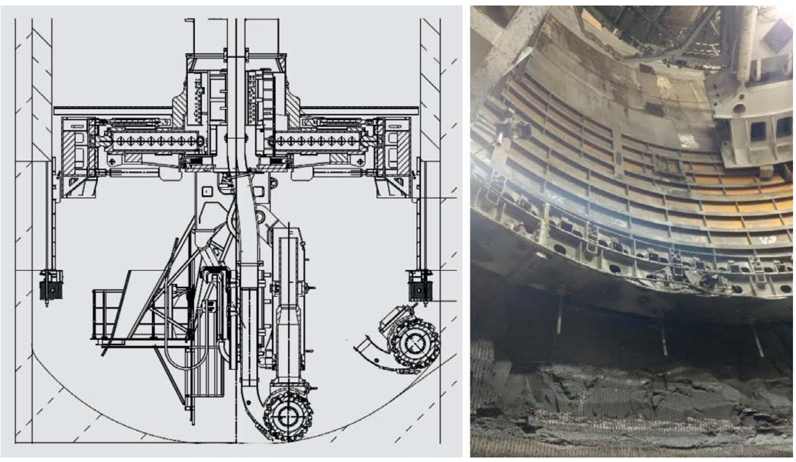

Fig. 23: The formwork is reduced in height and brought closer to the shaft floor in order to minimise the risk of further collapses.

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The Konrad Nuclear Waste Repository – Renovation and Reconstruction Work in the North Compartment of Konrad 1 Shaft

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The BGE (Federal Service Company for Radioactive Waste Disposal) is a Peine-based organisation that has been entrusted with the task of converting the former Konrad iron ore mine to serve as a final repository for low- and intermediate-level radioactive waste. The BGE is currently engaged in renovation and reconstruction operations at the Konrad 1 shaft site. After the refurbishment work in the south compartment of the Konrad 1 shaft was completed in 2016 with the successful commissioning of the new manwinding system the renovation of the north compartment was able to commence the following year.

Mining • Waste repository mining • Shaft construction • Conveying • Construction operation • Winding systems • Refurbishment

Project Background

The sinking of the Konrad 1 shaft commenced in 1957. The shaft, which was constructed to a diameter of 7 m, comprises a south and a north compartment and is supported with precast concrete blocks and brickwork. Sinking terminated at a final depth of 1,232.5 m and shaft insets were constructed at 1,000 m (level 3), 1,100 m (level 4) and 1,200 m (level 5). Ore mining ceased at Konrad in 1976 as a result of the unsuitability of the local ores for the smelting industry. The mine produced some 6.7 million t of ore during its lifetime. Even before ore mining finally came to an end the good geological conditions meant that early attempts were made to assess the mine's suitability for use as a final storage facility for radioactive waste material. By 1982 these investigations had concluded that the site was eligible to undergo a planning approval process for the construction of a final repository for low- and intermediate-level radioactive material. Following the positive outcome of the planning decision in 2002 and compliance with the relevant legal certainty requirements the conversion project commenced in 2007. The actual refitting work began at Konrad 1 shaft site in 2009 with the renovation of the south shaft compartment. Konrad number 1 shaft is to serve as a downcast shaft and will be used to supply the materials, power and other media required below ground. As the operator is required to ensure that in-shaft winding is available at all times the south compartment was retrofitted first while the north manwinding system continued to operate. Fitting work is now under way in the north compartment, with the south manwinding system serving as the transport route. Synchronising the shaft winding operations and the retrofitting work has proved to be a major challenge.

Corrosion Prevention Work on the Shaft Headframe

Following the conclusion of the renovation work in the south compartment most of 2017 was taken up by a complete renewal of the corrosion protection system on Konrad 1 shaft headframe. As the old anticorrosive paint contained red lead the entire headframe first had to be provided with a fully enclosed scaffolding system so that the corrosion protection coating could be properly removed. A negative-pressure environment was

Fig. 1: Descent being made by bucket to the mobile working stage in Konrad 1 shaft, 2018
Photos: BGE Bundesgesellschaft für Endlagerung GmbH

maintained in this area to ensure that no lead dust could escape into the air during the blast-cleaning operation. Manwinding and material transport services had to be maintained throughout this period and care had to be taken to ensure that no blasting dust was drawn into the downcast air system. The renovation operation involved the following:

- 24,000 m^3 of working area fully enclosed inside a scaffolding system
- 240 t of blasting abrasive consumed
- 5,000 m^2 of steel surfaces blast-cleaned and coated
- 8.2 t of new protective coatings applied

Renovation of the lower Rope Sheave Platform

After completion of the corrosion prevention operation in November 2017 work started on the refurbishment of the north compartment with the renovation of the lower rope sheave platform. The two pulley carrier plates were replaced in preparation for the twin rope sheaves that were to be used for the north winding installation. The sheave mountings were then extended and the rope sheaves that were no longer required were put to use for the stage system being set up in the south compartment. This stage was provided with six winches as follows:

- Two platform winches
- Two auxiliary winches
- A central winding system for the bucket (**Fig. 1**)
- An emergency travel winch for rescue missions using either the bucket or the working stage

In the winter of 2017 the temporary safety platform was installed at pit bank level and the mobile stage was put into operation in the north compartment. This travelling stage is composed of four decks as follows:

- Suspension deck
- Upper deck with extendible overhead protection plates
- Middle deck for the electrical power supply
- Bottom deck with fold-out side panels that can be used if required for covering the south compartment

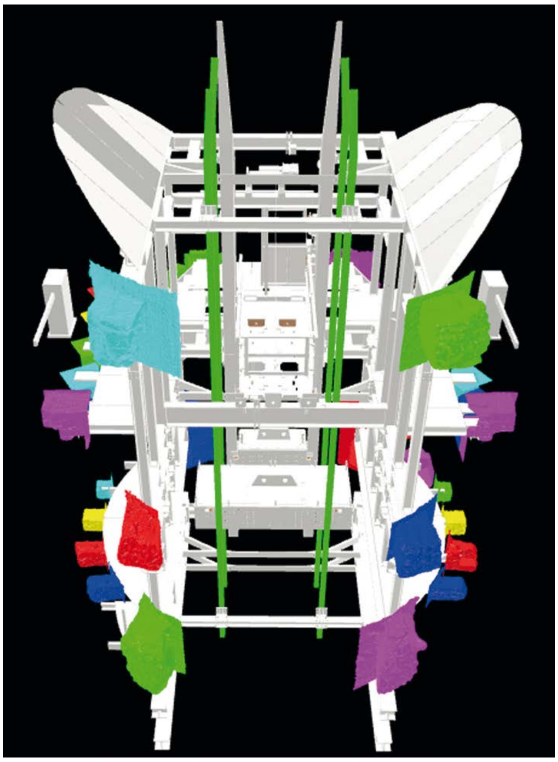

Fig. 2: 3D model of the shaft inset frame on level 5 showing the position of the holings

The mobile working stage has an overall height of 17 m and is fixed in place by two guide ropes. These are attached at their upper ends to a supporting beam mounted beneath the pit bank level and at their lower ends to a tensioning device set up in the shaft sump. The working stage has been designed so that it can safely access any point across the entire diameter of the shaft and carry out all the different tasks as and when required.

Removal of Shaft Fittings

The first phase of the renovation work required in the north compartment comprised the removal of the old shaft fittings. A system of wooden buntons spaced vertically 1.5 m apart had been set into the brickwork over the entire length of the shaft. The wooden guides used for the original north and south winding systems were fixed to these buntons. The south guides and buntons had already been removed as part of the renovation work undertaken in the south compartment. The refurbishment of the north compartment subsequently involved stripping away the east, west and central buntons along with four runs of wooden guides. In some areas these guides were directly set into the shaft brickwork and in others they were surface-mounted on steel brackets. After this work had been completed the shaft inset frames on levels 3 (–1,000 m), 4 (–1,100 m) and 5 (–1,200 m) were also removed. This operation involved the following individual tasks:

- Removal of 21 km of wooden guides and fittings
- Filling of 3,200 brickwork openings with shotcrete
- Detachment of some 1,600 steel brackets
- Removal and disposal of 130 t of steel

The removal of the shaft fittings created the free space that was needed for the new rope-guided north winding system. The stripping-out of the old timber elements also served to reduce the fire load present in the downcast ventilation shaft.

Survey Measurements and Preparation of a 3D model

When the work of removing the old inset frames had been completed the clear lines of sight this created enabled a site survey to be carried out using a laser scanning process. After the structural foundation elements had been set in place another site survey was undertaken in order to check the relevant system dimensions.

The measurement results were interlinked and together with the data for the inset frame were combined to produce a joint 3D model (**Fig. 2**). As a result any slight deviations, for example in the position of the slots and holings, could be identified in advance and then rectified. This approach also served to verify that the supporting lengths along the centre line of the buntons were effectively in place, as laid down in the relevant

Technical Requirements for Shafts and Inclined Winding Systems (TAS 2.4.3.1) [1].

Installation of three new Shaft Inset Frames

Three new inset frames are currently being installed on mine levels 3, 4 and 5. The fitting of the new shaft frames is described below using as an example the installation of the inset frame on level 5 (**Fig. 3**).

Preparing the Foundations

After the process of removing the old inset frames had been concluded the concreting work could begin in the shaft landings to construct the foundation elements for the new shaft frames. This operation involved preparing some 22 holings for fixing the frame supports in the shaft brickwork, carrying out formwork and reinforcement tasks and constructing the reinforced concrete bearings that would serve as load transference points in the insets.

The excavated material, which was produced in significant quantities, was either winched out in the dirt buckets or transported away in trough containers. On arriving at the surface the waste underwent sample testing for contaminants before being disposed of.

Installation of the Inset Frame on Shaft Level 5

The inset frame, which is located on mine level 5 at a depth of 1,200 m, marks the deepest end point for the future rope-guided main rope winding installation in the north compartment and the central winding system in the south compartment, which will run on rigid guides (**Fig. 4**).

The steelwork for the inset frame on level 5 is made up of three inset frame supporting decks positioned at depth levels of between 1,202.5 m and 1,196.2 m. The decks are fixed into holings in the shaft brickwork or set on new reinforced concrete foundation elements.

The shaft inset frame on level 5, which is at a depth of 1,205.5 m, is carried on two HEB 900 frame support beams. These beams are set in a north-south direction, measure 7,250 mm in length and each weigh 2.6 t. When finally assembled the inset frame, including all its installations and attachments, will have an overall weight of around 51 t.

During the later operational phase a balance-rope inspection platform, which can be lowered beneath the north winding conveyance, will be available for use in the north zone of the inset frame. The counterweight for the rope-guided north main rope winding installation can in addition be set on retractable catches, while both winding conveyances can also be individually set down on a further set of catches positioned within the inset frame on level 5.

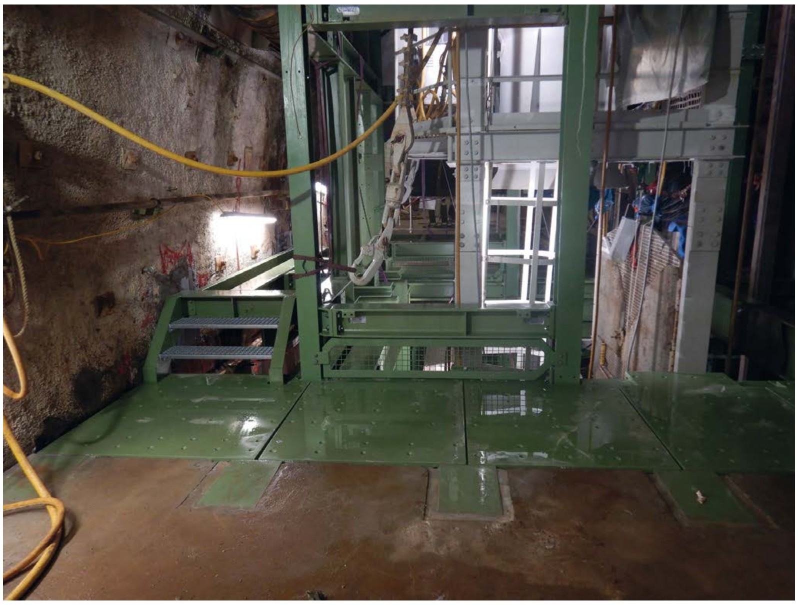

Fig. 3: Shaft inset frame on mine level 5 viewed from the west shaft landing

Fig. 4: Shaft inset frame on mine level 5 viewed from the east shaft landing

A forklift system operating on the apron of the west shaft landing zone will be available so that the north shaft conveyance can serve as a materials handling point.

Preparations for the Installation of the Shaft Inset Frame

Before work commenced on the erection of the new inset frame two temporary platforms were installed above level 5 at a depth of 1,169 m to ensure overhead protection for those engaged in the assembly work beneath. This meant that cover was provided for the side areas of the shaft cross-section near the winding conveyance of the central rope winding system in the south compartment.

During the preparatory phase of the operation a number of associated tasks had to be carried out, in-

Fig. 5: North shaft winder with drive

cluding the demolition of some of the existing concrete foundations that would no longer be required, the reprofiling of parts of the shaft support system, the removal of some old sections of the inset-frame support beams and the break-up of the old decking level and its replacement with a new concrete floor. A large number of fittings and items of technical equipment were also relocated or temporarily deconstructed.

Delivery of Steel Components and Girders

The smaller steel components were delivered in advance by the south shaft conveyance and then temporarily stored close to the shaft. The main beams were dispatched in their specified installation sequence before being suspended beneath the middle rope winding system in Konrad shaft number 1 north and escorted to their installation position. They were then transloaded and manoeuvred into a horizontal position by means of the auxiliary winches mounted on the mobile working stage. The main beams were also fastened to slinging brackets before being manoeuvred into their installation positions, adjusted and aligned and then set on stiffener plates. Despite measuring up to 7,250 mm in length the girders could be installed without site joints as the north end of each steel beam was simply lowered into an open-topped recess in the inset floor.

After the exact positions of the steel beams had been measured and subsequently approved by a specialist surveyor the engaged holings were potted with expansive grout of strength class C 25/30.

Main Steelwork

Secondary beams were connected up to the grouted HEB 900 main girders at the lowest level of the inset frame. Various attachment parts were then fitted and hydraulic wrenches were used to tighten the high-tensile bolts to the required torque levels before the next level of beams above were brought in, aligned and grouted into place. After the main steelwork had been erected the movable attachments and exposed surfaces were packed in rubber mats and textile sheeting to protect them from any falling construction debris.

Precision Assembly

The subsequent completion work included the installation of the electrical components, such as drives, hydraulic systems, cable brackets, controllers and decking gates. The shaft inset frame on level 5 was then ready to play its part in future waste repository operations.

Shaft Winder for Konrad 1 North

At the beginning of 2022 work started on the construction and commissioning of the new shaft winder in Konrad 1 north, this being undertaken in parallel with the installation of the new inset frame (**Fig. 5**). The winder, which will serve the main rope winding installation for Konrad 1 shaft, will operate as a ground-mounted machine in the newly constructed winding house north. Designed as a twin-rope Koepe winder the new machine will eventually carry maximum payloads of 15 t for material transport duties. The skip-type conveyance consists of two decks, the lower of which has to be adapted for material transport purposes. This waste material will come from the excavation of the storage chambers that will be driven successively and in parallel with the ongoing disposal of the radioactive material that will eventually form part of the long-term repository operations. The debris in question, which will mostly comprise iron ore, will not be processed in any way but will be taken by a belt conveyor and loading system to a separate rail link for transport to the final disposal site.

Technical Data on the Shaft Winder for Konrad 1 North

When the installation is being operated solely for manwinding purposes each winding cycle can carry a total of 32 persons using both conveyance decks. The maximum travel speed for materials conveying is 16 m/s and for manwinding 12 m/s.

The friction drum on the new winding machine is 5 m in diameter and is connected to the engine shaft via high-tensile bolts. The shaft is mounted on two plain bearings, one being a floating bearing and the other a fixed bearing. The oil supply to both bearings is located in the cellar of the winding house. As well as having circulating oil lubrication both bearings also feature a hydrostatic starting system that is designed to reduce bearing wear. The faces of the winder's two brake discs are bolted to the friction drum. The system has a total of eight pairs of brake force generators, these being mounted on four brake posts that enclose the brake discs on both sides. The braking force is generated by means of plate springs and is then transferred to the discs. The brake shoes are released hydraulically. The friction drum lining has a twin groove surface. A turning device for the drum lining is located in the winding-house cellar below the friction drum.

The winder is driven by a three-phase synchronous motor with a power rating of 1,750 kW. The motor has a total weight of about 32.5 t. The friction drum is connected via the shaft to the drive motor. The rotor of the drive motor can be adjusted horizontally on the motor frame for maintenance and servicing purposes and so the rotor unit that is flange-mounted on the shaft can also be accessed when carrying out work of this kind. The drive motor is cooled by a separate ventilation system that is located in the cellar of the winding house.

Commissioning of the Shaft Winder for Konrad 1 North

Once the work of installing the mechanical and electrical components for the new winding machine in Konrad 1 north shaft has been completed in mid-2022 the winding rope can be fitted and the north winding installation can then be put into service in 2024.

This schedule has been imposed by the need for a complete reconstruction of the guide frame serving the Konrad 1 shaft installation. The original guide frame was designed to operate as a shaft sinking frame and was kept in service as a guide frame when the shaft sinking work was concluded. For the future operation of the rope winding installations at Konrad 1 shaft north and south the old guide frame will have to be completely dismantled and a new guide frame installed. This time-consuming assembly phase will impose a halt of several months to rope winding at Konrad shaft and only when this work has been completed it will be possible to commence operations with the new shaft winder at Konrad 1 north.

Outlook

With Konrad 2 shaft being used for transporting the radioactive waste to the underground storage chambers Konrad 1 shaft north will play its part in future repository operations by acting as a manwinding and materials conveying shaft and as a transport route for the removal of excavation debris. The shaft winder at Konrad 1 south, which came into operation in 2016, will then be used for the transportation of materials and heavy goods.

In addition to the ongoing work of renovating the winding shaft, erecting the three inset frames and installing the new north winding machine other tasks on the agenda include the replacement of the guide frame, the construction of a surface belt conveyor and loading system and the commissioning of the rope winding installation for Konrad 1 shaft north. These key project milestones will ultimately result in a fully retrofitted Konrad 1 shaft and an operationally ready Konrad waste repository facility. The re-fitting work in Konrad 1 shaft is due for completion in 2025 and final commissioning of the Konrad repository is scheduled for 2027.

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GeoResources Journal and Zeitschrift

Time and Subject Schedule 2023*

Four English and four German issues of GeoResources are planned for the year 2023. You can find the publication dates and the special topics below. Regular features in every issue are:

A Word on ... / Auf ein Wort
•
Geotechnics / Geotechnik
•
Tunnelling / Tunnelbau
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Mining/Raw materials / Bergbau/Rohstoffe

These regular features are covered in all issues. Articles of these sections also address energy and sustainability aspects. Our motto is: We place the underground in the foreground! Furthermore, we are dedicating each issue to a special topic. The special topic can be taken up in every regular feature. As always, we will make our journals available to all readers online. Prints are available. At interesting professional events, we will bring the issues to the attention of participants in print. Articles are welcome. Please feel free to contact us for further information.

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Journal	2|2023	May-09-2023 (CW19)	Geotechnics, Tunnelling, Mining/Raw materials **Special:** Focus on raw material security and supply chain
Journal	3|2023	Sep-19-2023 (CW38)	Geotechnics, Tunnelling, Mining/Raw materials **Special:** Focus on fairness and skilled workforce
Journal	4|2023	Nov-28-2023 (CW48)	Geotechnics, Tunnelling, Mining/Raw materials **Special:** Focus on mobility and heat transition

German Issue		Publication Date	Topics
Zeitschrift	1|2023	Feb-07-2023 (CW6)	Geotechnik, Tunnelbau, Bergbau/Rohstoffe **Spezial:** Natur und Klima im Fokus
Zeitschrift	2|2023	Apr-18-2023 (CW16)	Geotechnik, Tunnelbau, Bergbau/Rohstoffe **Spezial:** Rohstoffsicherheit und Lieferketten im Fokus
Zeitschrift	3|2023	Aug-01-2023 (CW31)	Geotechnik, Tunnelbau, Bergbau/Rohstoffe **Spezial:** Fairness und Fachkräfte im Fokus
Zeitschrift	4|2023	Oct-24-2023 (CW46)	Geotechnik, Tunnelbau, Bergbau/Rohstoffe **Spezial:** Mobilitäts- und Wärmewende im Fokus

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