Mine Closure 2016 – AB Fourie and M Tibbett (eds)

doi:10.36487/ACG_rep/1608_0.1_von_Bismarck

The importance of failure in mine closures

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Abstract

When delegates from companies present papers at conferences, the word most frequently cited is success. This is very understandable but an important aspect of being successful is the ability to look honestly at failure. Failure is often stigmatised; rarely is it talked about in the open.

The major challenge in mine closure is – and this is something that probably holds true for everybody involved in the process – finding the optimal path that runs between overestimating or underestimating risks. Taking a closer look at failures helps us to find that path. Planners and engineers, even the most well-regarded experts and regulators, are human. Their preconceptions may be mistaken, leading them to the wrong conclusions. Sometimes such assumptions are long-standing beliefs, their true worth hidden until failure reveals them to be false.

In his famous 1948 work 'Cybernetics: Or Control and Communication in the Animal and the Machine', Norbert Wiener laid the foundations for controlling systems and ensuring reliable communication by explaining the essential role of negative feedback in a self-educating system. Mine closure can be considered as such a system. Our attempts to self-educate, such as at international conferences, require negative feedback, or, in other words, an honest assessment of our mistakes.

Many success stories could be told about the German Government's EUR 10 billion, 25-year coal mine rehabilitation programme in the former East Germany. But those involved in the project encountered significant failings, too. In this paper, I present some of those failures in the field of geomechanics and what we have been able to learn from them.

For decades, engineers relied on formulas based on established geomechanical models to determine the stability of dumped and levelled waste material. The results of these model calculations were accepted by regulators as no better methods were available. Since 2009, several ground-breaks have proved that these models are incomplete and the process has not yet been fully understood. The long-standing assumption that dumped waste material settles slowly and evenly was evidently untrue. Additionally, the belief that only exogenous forces can trigger a ground-break was found to be false.

These mistakened assumptions had severe consequences. As the areas had been deemed stable, the land had already been sold by the mining company and had been in use for several years for activities, including agriculture and forestry. It is truly fortunate that the ground-breaks did not cause any casualties.

In the wake of these ground-breaks, all areas of dumped waste were re-evaluated. Access to thousands of hectares of land was barred as a precautionary measure, which in turn delayed the rehabilitation process and necessitated compensation costs for farmers and forest owners. At the same time, more investment became necessary for further research and development (R&D) to come to a better understanding of the process and to develop new and specialised stabilisation measures.

This re-evaluation of the waste dumps would pinpoint areas with potential stability deficits, where new technologies such as gentle-blast-compaction have now been applied. These lessons had to be learned the hard way.

1 Introduction

For many centuries, mining has been an indispensable part of human existence on every continent. Like no other area of life, it stands for the conflict of man with nature, extracting resources from the earth to preserve and develop humanity. Alongside agriculture, mining provides the material substance for modern societies. It strengthens economies, advances science and technology, and fuels personal prosperity. Quite simply, without mining, the entire history of human social development is unthinkable. It is a core principle of successful human action.

But the long history of mining, underground or open pit, carries with it many negative associations and failures: the destruction of landscapes, damage to natural environments, and the demolition of infrastructure, as well as accidents and the memories of the innumerable miners who have lost their lives at work.

Discussing successes, especially at a conference, makes a great deal of sense. But a fair and thorough consideration of failure is central to any success. Admitting error and failure is a necessary part of improving the mining industry.

This is especially true in political spheres where hardly anybody talks openly about their failures. Opposition parties may emphasise the failures of those in power but they are rarely as clear-eyed about their own shortcomings, and never as vocal. Similarly, one rarely encounters systematic approaches to failure in public services and other governmental organisations, despite the essential role of negative feedback for learning in a system having been established as early as 1948 (Wiener). Failure and success are two sides of the same coin. Stories of success create valuable lessons only when combined with those of failure.

Mining is typically a long-term business. If, at the beginning of this process, the economic opportunities of mining draw most attention, mine closure tends to focus on the abiding risks of an operation. To evaluate the risks of mine closure, particularly in the long-term, you need to rely on assumptions that allow you to prepare for future scenarios about which information is necessarily limited. Over time, those assumptions directly determine the success or failure of a mine closure operation.

It is in the interests of every stakeholder in the rehabilitation of a mine that the risks of that process are neither exaggerated, nor unduly dismissed.

Certainly, stakeholders apply different priorities to their estimations. Regulators might want to err on the safe side and may tend to overestimate possible risks. In contrast, mine operators may tend to underestimate risks as they seek to fulfil their legal obligations to secure the post-mining landscape in the most economical and efficient ways. When these different opinions on potential risk differ too much, all stakeholders suffer as the entire operation struggles to find a balance between being sustainable and being practically effective.

Taking a closer look at past failures can provide a guide to help us negotiate the best path through this situation.

However, well-regarded planners, engineers and other experts are prone to human error. They may hold mistaken preconceptions that lead to inaccurate conclusions. Sometimes such assumptions are long-standing beliefs. It is only when failures occur that such articles of faith are called into question.

Failure in a mine closure process can emerge from any quarter. Typically, problems are:

- Social, such as when the assessment of a social situation is mishandled, sparking protests that may hamper or block the process.
- Economic, with poor budgeting for the financial requirements of mine closure.
- Organisational, as when structures at mining companies or regulators hinder the efficient flow of information available for decision-making.
- Legal, including instances when applicable regulations are not noted during the process, or have changed.
- Technical, when a specific rehabilitation technique does not achieve its goals or when assumptions about the geo-hydrological situation are incorrect.

The length of this paper does not allow for a discussion of illustrative case studies in every variant of failed mine closure. It discusses examples of recent failures in Germany in the field of geomechanics, along with what we can learn from them.

2 Recent geomechanical engineering failures in Germany (2007–2015)

In 1989, East Germany was the largest producer of lignite coal in the world (Figure 1). By the early 1990s, about 80% of this industry had been forced to close in the wake of German reunification, as mines and plants were either deemed uneconomical or found to be unable to meet rising environmental standards. Production fell from 300 million to 70 million tonnes of coal per year. The mines that were able to remain in operation were privatised, while the government assumed liability for the larger part of the industry that had been closed down (von Bismarck 2012).

Figure 1 Lignite mining districts in an area of former East Germany

In the Lusatia mining district alone, 56 large scale open-pit mines were closed between 1945 and 1999, leaving behind 850 km² of previously mined land. Apart from a significant number of residual holes or voids that will ultimately form after flooding, about 280 km² of new lakes, the principle legacy of these mines, are un-compacted overburden dumps.

In 1992, a unique government programme to rehabilitate former East Germany's closed mines, processing plants, cookeries and power stations began. This EUR 10 billion, 25-year project was often very successful, but there were failures, the consequences of which still cause problems.

Primary emphasis in the rehabilitation process was given to stabilising over 1,000 km of slopes on overburden dumps, as part of the preparation of the voids as future lakes (Figures 2 and 3). Several technologies were applied in this stabilisation process, principally blast-compaction and vibro-compaction, while within the slope itself a hidden dam was created to avoid settlement-flows triggered by the rebound of groundwater levels that had been artificially lowered during coal production (Figure 4). Sandy waste material, in particular, can cause such landslides through spontaneous soil liquefaction which may occur without warning.

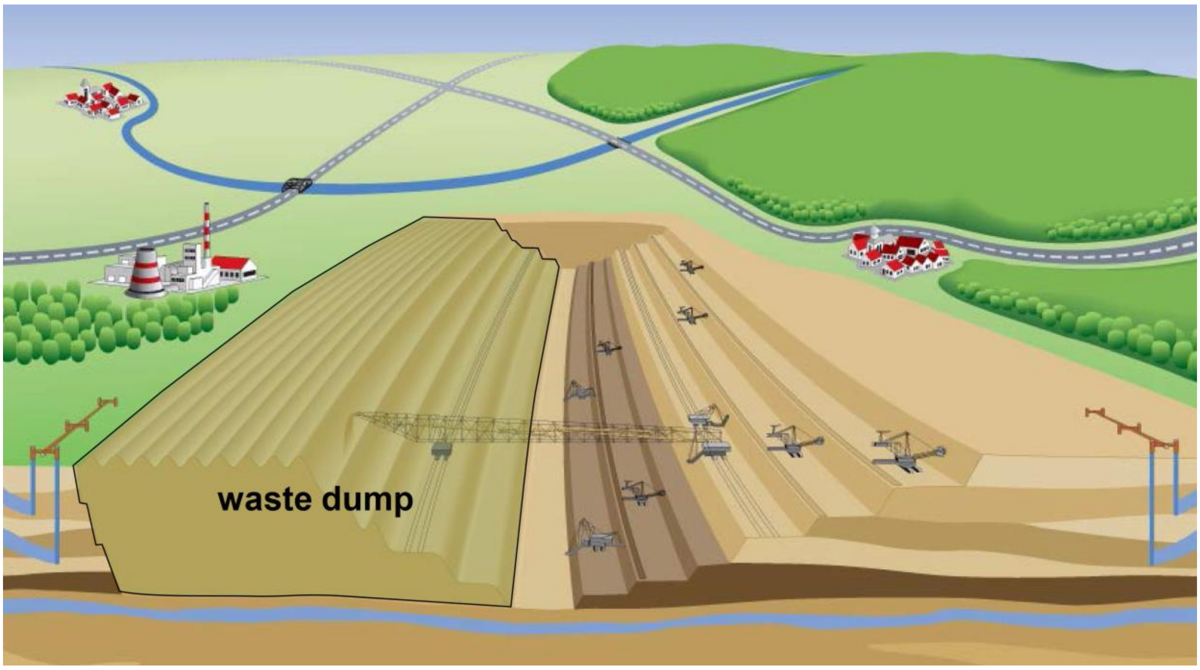

Figure 2 Waste dump in a typical open pit coal mine in the former East Germany

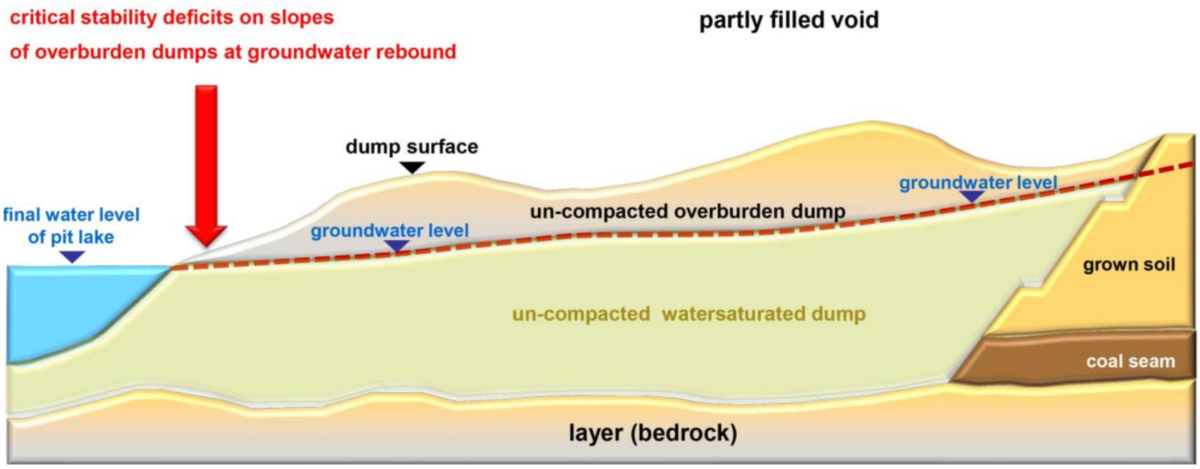

Figure 3 Section in an overburden dump with the tendency for a settlement-flow (initial situation)

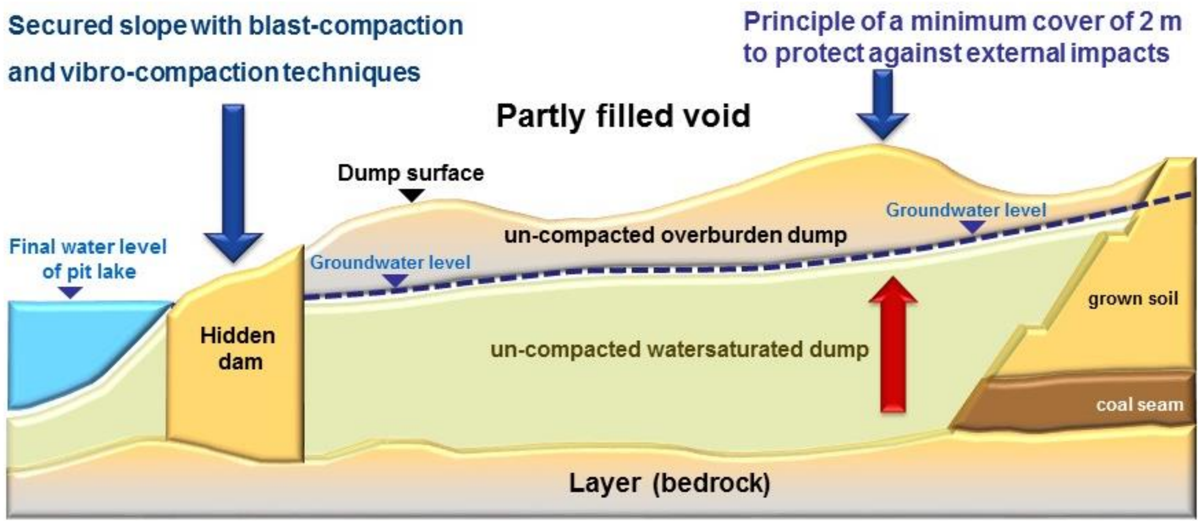

Figure 4 Section in a waste dump with a hidden dam and direction of inner initials (impacts)

For the rest of the waste dumps, it was assumed that dumped and levelled overburden material would settle slowly and evenly. This assumption was founded on formulas based on geomechanical models that had been used by engineers for decades to determine the stability of dumped waste materials. In the absence of better methods, these calculations were accepted by mining regulators and led to the rule that an artificial cover of 2 m or more above groundwater level would be sufficient to stabilise the surface of the dump. The fulfilment of these two principles for the stability of waste dumps – a hidden dam for the slopes and a minimum cover of 2 m above groundwater level – reflected then state-of-the-art science and rehabilitation methods.

In 2007, the first spontaneous ground-break appeared in the Lusatia mining region. It was considered serious but an isolated event. However, when more cases of unexpected instability on uncompacted waste heaps followed in 2009 (Kuyumcu & Zschiedrich 2012), everybody involved in the rehabilitation process was forced to recognise that these cases of liquefaction were part of a new phenomenon neither sufficiently understood by science, nor subject to practical methods of damage control.

In the period since, the number of instances of liquefaction and ground-breaks has risen above 50 (Kudla et al. 2014). Evidently, something is missing in our geomechanical models. The long-standing assumption that dumped waste material settles slowly and evenly is untrue. What's more, the belief that only exogenous forces can trigger a ground-break appears to be false.

Experts now do not dispute that the rebound of the groundwater level led to the saturation of the non-compacted dumps, leaving some areas with only a minor distance between the heap surface and the groundwater level. Clearly, such conditions are capable of creating latent instability in dumps or heaps. However, although incidents of liquefaction may have been influenced by external supporting factors such as heavy rainfall and extended periods of frost (Kuyumcu & Zschiedrich 2012), there remain questions about what caused them which we are still not able to answer. In particular, the delimitation and interaction of supporting factors and impact that trigger sudden liquefaction (Kudla et al. 2014).

Reality has, at least temporarily, overtaken science.

Soil liquefaction is a sudden loss of shear strength following the collapse of the granular structure leading to meta-stable suspension (Weißbach & Kudla 2012). Certain strains within a dump may lead to a local collapse with uncontrollable chain reactions of liquefaction.

The most severe incident of a complex voluminous soil liquefaction occurred in 2010, in an area of the former Spreetal open pit mine (Figure 5). A year later, shortly after stabilistion works with vibro-compaction had started, a ground-break happened in the Seese-West mine (Figure 6). Most probably it was triggered by the mechanical impact of the works. Another major ground-break had to be observed in 2015 at the former Schlabendorf-South mine that also destroyed a street (Figure 7).

The consequences of miscalculating the stability of these areas proved grave. Although no lives were lost as a consequence of the ground breaks, the areas of rehabilitated land had been deemed stable and sold on, and had been in use for years for activities, including agriculture and forestry.

One possible direction in the search for answers for what caused the unpredicted liquefaction can be the fact that soil properties in an engineered landscape can change during the process towards a stable ecological system and these changes can alter system performance. In addition, weathering of the cover system can result in changes to the physical characteristics of the material performance (DeJong et al. 2014).

Figure 5 Ground liquefaction at the former Spreetal mine in 2010. Source: Lausitzer und Mitteldeutsche Bergbauverwaltungsgesellschaft (LMBV)

Figure 6 Ground-break near Kittlitz in the Seese-West mine in 2011 (source: LMBV)

Figure 7 Ground-break at a street at the former Schlabendorf-South mine in 2015 (source: LMBV)

3 Actions taken

It became apparent that, in any case, a longer time with intensive research work will be required to produce additional quantifiable factors that, apart from the known geotechnical and geo-hydrological factors, also played a critical role for the loss of soil stability.

Before details of a correlation between ground-breaks and liquefaction could be fully established, it was apparent that major action had to be undertaken immediately.

A number of action plans were drawn up combining short-, mid-, and long-term measures, including:

- Barring access to 22,900 ha of land as a precautionary measure, thus delaying the rehabilitation process and necessitating compensation for farmers and forest owners.
- Forming an expert geotechnical advisory body to conduct a scientific oversight of research.
- Installing early warning systems for sensitive objects, e.g. streets.
- Creating a database for the systematic analysis of waste dumps, including the re-evaluation of geotechnical stability.
- Testing new stabilisation technologies such as gentle-blast-compaction and the drainage of dumps.

Regulators at LBGR Brandenburg, the regional government mining inspectorate, concluded that further compaction of the waste dumps was necessary to create a secure landscape (Cramer et al. 2014).

Their demands were justified with the following arguments:

- Potentially dangerous areas of the dumps had already been in use for forestry and agriculture.
- The predicted final level of groundwater proximity to the surface had already been reached and possibly exceeded.
- There was a strong public interest in the reuse of the formerly-mined land, e.g. for tourism.
- It would be practically impossible to keep the public, i.e. hikers, fishermen or mushroom collectors, out of the restricted areas.

The appropriate technology to permit sufficient further compaction of the dumps at a reasonable cost was not yet available. The restricted areas could not be accessed with normal heavy compaction technology. More investment in R&D was necessary in order to come to a better understanding of the liquefaction process and to develop new and specific stabilisation measures.

4 Results

After several years of intensive work involving wide-ranging interdisciplinary discussions with scientists, experts and regulators, the first proposals to make the waste dumps safe were ready to be presented by the scientific advisory body (Scholz 2014). In short, these were:

- To develop an integrated waste-dump security evaluation system to generate a risk-prediction map assessing the probability of ground breaks (Figure 8).
- To build up a long-term monitoring system to follow geotechnical events.
- To apply synthetic drains to reduce the pore water pressure in especially sensitive areas, such as streets.
- To develop a re-evaluation system for dumps and voids using pressure sounding.
- To advance the development of new technology for gentle-blast-compaction.

Meanwhile a number of rehabilitation measures are being successfully applied. A seismic alarm system combining input data, including topography, land use, dump structure, kf-value, groundwater rebound and slope angle (Figure 8) was installed in 2015. The re-evaluation of the dumps had been completed, together with the identification of stability deficits.

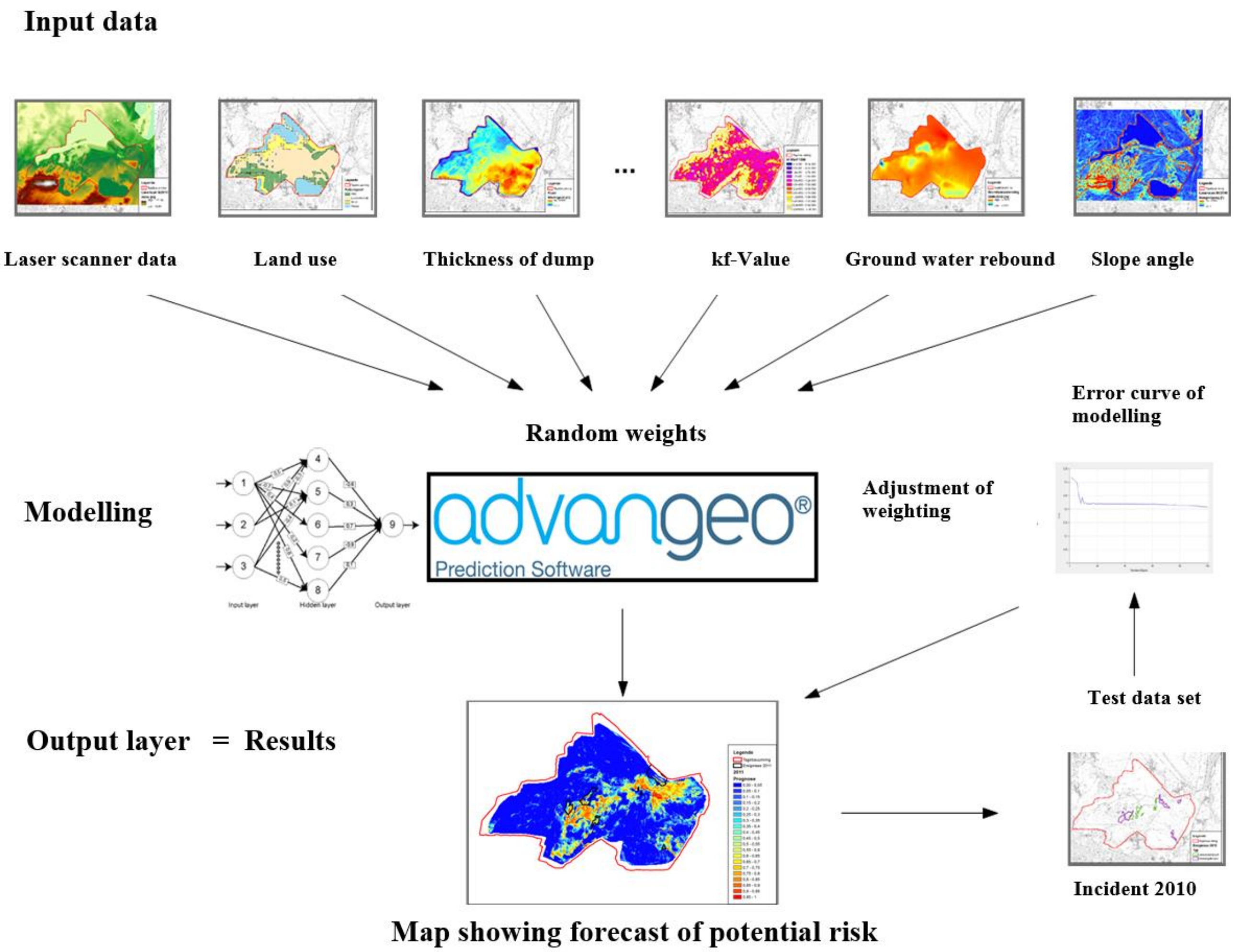

Figure 8 Configuration of the integrated waste-dump security evaluation system (IKSB). Source: Beratende Ingenieure für Umweltgeotechnik und Grundbau (BIUG)

On this basis a new technology of gentle-blast-compaction has been developed and tested.

The underlying idea (Erler 2012) has been to apply a series of shallow underground blasts just below the groundwater level (up to 20 m deep), in order to stabilise areas of previously non-compacted heaps and dumps that are otherwise impossible to access with the heavier technology normally used to stabilise slopes, such as blast-compaction and vibro-compaction. First tests were conducted with relatively short distances within the blasting grid (of between 10 and 24 m) and explosive loads of 6 to 7.5 kg of ammonium-nitrate per hole (Figure 9).

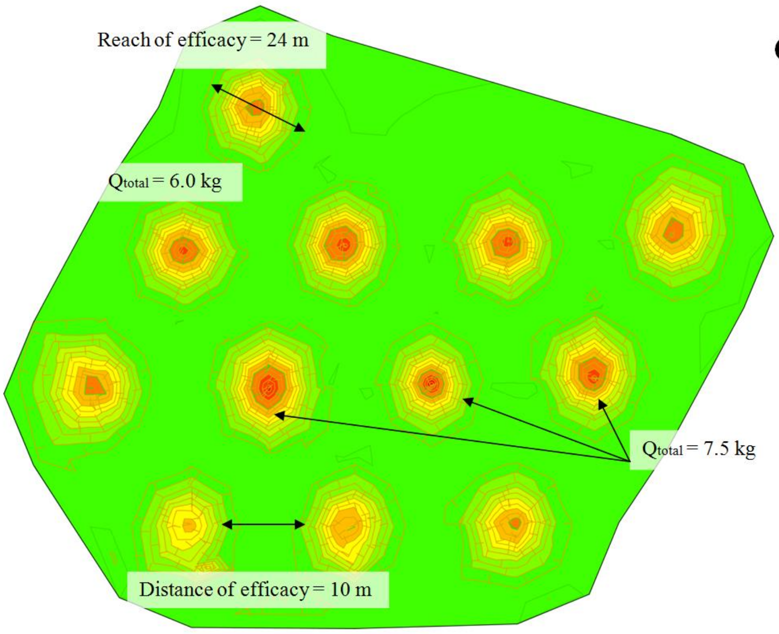

Table with height changes in meters

number	min. value of height	max. value of height	color
1	-1600	-1400	
2	-1400	-1200	
3	-1200	-1000	
4	-1000	-800	
5	-800	-600	
6	-600	-400	
7	-400	-200	
8	-200	200	

Figure 9 Principal of gentle-blast-compaction. Source: BIUG

By carefully timing detonations vertically and horizontally, shockwaves were further synchronised to improve the stabilisation effect and avoid collateral damage. Following these tests (Figure 10), the loads could be reduced to only 0.5 kg of explosive per hole, and the optimal blasting grid distance was found to be 15 to 30 m.

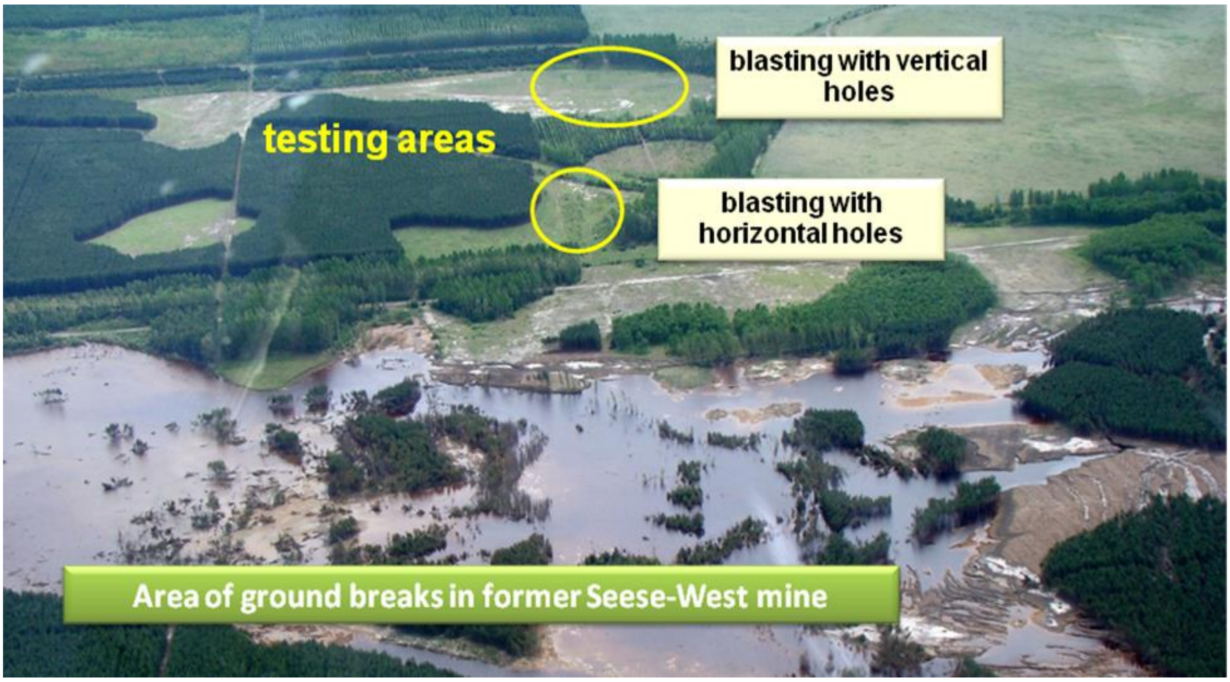

Figure 10 Gentle-blast-compaction tests from December 2012 to June 2013 in the former Seese-West mine. Source: BIUG

Naturally the configuration of gentle-blast-compaction is altered according to specific regional conditions.

However, even if this new technology proves to be a complete success, its relatively high costs in terms of resources and time mean we are still in need of alternative methods.

5 Lessons learned

In this instance, assumptions about the geo-hydrological requirements for stability were false and led to failure. They had proven to be reliable many times in the past. So often, in fact, that they were not questioned. Now we know that they cannot be applied at previously uncompacted heaps and dumps.

We have learned that we have to cross old borders and take a broader interdisciplinary perspective for our mine closure work and we have understood that we will need considerable more effort before we can reach the goal of a sustainable post mining landscape. Now, armed with that knowledge, we have had to develop a new technology to tackle the problems of ground-break and soil liquefaction.

Successful technologies and methods are the building blocks of progress but they all begin as responses to failure. Understanding the inadequacies of existing methods, questioning our assumptions, and exploring the limits of our knowledge are absolutely fundamental elements of mine closure. Ultimately, because they improve our work, every stakeholder in the mining world benefits from a better understanding of the problems we face and the ways we overcome them. Almost all rehabilitation projects encounter false starts and dead ends. It is these misdirections that lead us to the correct path. I urge you to share them with each other in a constructive, collaborative atmosphere of trust.

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