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Distribution and damage potential of acidic and sulphatic groundwater in Germany with particular regard to the re-rise of groundwater – Part 1: State-of-the-art report

SHORT REPORT

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1 Aim of the research project

Various regions in Germany may reveal increased acid and sulphate concentrations in the groundwater. While low pH-values (pH < 5.5) lead to a solving attack on concrete, a long time ingress of sulphate ions (> 200 mg/l SO_4^{2-}) results in expansive or destroying reactions in the concrete. Aggressive concentrations of acid and sulphate at specific locations are often only temporary (e.g. due to accidents in the chemical industry), so that the slow corrosion processes do usually not cause a significant damage to the concrete structure. Over a wide area increased acid and sulphate concentrations occur in regions with iron disulphidic soil components e.g. pyrite. These components oxidise and release in particular iron, sulphate and protons (acid). The spacious access of oxygen may result e.g. from the lowering of the groundwater level in areas. Over the years the oxidation products accumulate mostly in the aerated soil layers of the cone of depression and are only partially removed through seepage into the groundwater. This problem is exacerbated by the mine dumps which are also present in these regions. In those a particularly intense oxidation of iron disulphidic overburden material occurs that causes consequently a massive release of acid and sulphate.

Although the location and the size of the currently affected areas are known, a huge amount of concrete-aggressive oxidation products of iron disulphide in their soils can be mobilised by the future re-rising of groundwater when the draining/pumping is ceased at the end of mining operations. Consequently, the mobilised oxidations products will be transported towards the surrounding environment. An assessment and evaluation of the current and the future groundwater situation in mining regions and their attack potential for buildings have not been established yet. The basis for these complex and comprehensive issues is given by this research project financially supported by the research initiative "Zukunft Bau" on behalf of the german Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR) in the Federal Office for Building and Regional Planning (BBR). The objectives of the research project were:

- Compilation of available data about the current and future groundwater situation in mining regions, in particular the development of the groundwater quality over time with respect to acid and sulphate concentrations
- Evaluation of the aggressiveness of groundwater (influenced by mining operations) against concrete under consideration of investigations on deteriorated structures
- Development of first recommendations for effective protection measures in case of concrete attack by acidic and sulphatic groundwater

2 Execution of the research project

For the identification and evaluation of the areas with acidic and sulphatic groundwater information was collected from various sources such as environmental agencies, regional offices and universities. The resulting overview should demonstrate the current and future (after cessation of drainage for mining operations) affected regions as well as the current and future depths and quality of groundwater with respect to sulphate, pH and carbonic acid. However, the data basis determined within the research project was limited on single aspects and locations only (e.g. current acid and sulphate concentrations of individual groundwater control points). The development of the groundwater quality in the vicinity of mining areas were described using the example of the Lusatian and Central German as well as the Rhenish mining area, for which there is only little detailed knowledge available. Important information is provided by the most recently published dissertations of GRAUPNER [2] and LENK [3].

On basis of the characteristic properties of groundwater influenced by mining operations the potential for concrete attack is evaluated with regard to essential factors e.g. transport conditions, concrete composition etc. Since there is a lack of comprehensive knowledge about the groundwater levels (at the end of groundwater re-rising), the flow conditions and the transport direction of the aggressive media in combination with the foundation depth of existing building structures, the extent of damage due to the concrete attack by contaminated groundwater from mining areas cannot be described quantitatively accurate. The attack potential of groundwater mineralised by the oxidation products of iron disulphide on concrete structures is therefore evaluated on basis of current research results about the combined acid-sulphate attack on concrete and results derived from studies on concrete structure damaged by acid and sulphate attack. By means of the available knowledge about the deterioration mechanisms in concrete under the impact of acidic and sulphatic water the progress of corrosion can be assessed appropriately for characteristic attack scenarios taking into account significant constraints. In order to counteract the potential attack of acidic and sulphatic groundwater on concrete structures effectively, measures are described which reduce the degree of attack of the aggressive medium or increase the resistance of affected structures. For this purpose single methods proven in practice are presented exemplarily.

3 Summary of the results

3.1 Locations with acidic and sulphatic groundwater

Increased acid and sulphate concentrations in groundwater occur rather seldom in Germany. The causes for the occurrence of increased acid and sulphate concentrations in groundwater are diverse. Often the reasons are anthropogenic. For example, discharge of industrial waste water, accidents in power plants or in the chemical industry etc. can locally change the chemical composition of groundwater significantly. However, increased acid and sulphate

concentrations, which exhibit a chemical attack on concrete over a long period of time, are not caused by such temporary "point" sources. [1]

Significant effects of anthropogenic influences on the groundwater quality usually occur in areas where iron disulphides are present and oxidation of theses minerals take place. The oxidation of iron disulphide proceeds on large-scale and over a long period of time mainly in coal-mining regions. On the one hand the lowering of groundwater in mining areas may lead to aeration and oxidation processes in deeper soil layers with iron disulphides. On the other hand oxidizing iron disulphidic soil material is deposited on mining dumps and releases a significant amount of sulfuric acid and iron sulphate which is washed out by seepage into the groundwater. If the soil in such areas is simultaneously rich in carbonates, the released acid might be buffered partially or completely. While partial buffering leads to increased loads of sulphate and carbonic acid, complete acid buffering limits the contamination of groundwater to increased sulphate concentrations.

With re-rise of the groundwater a major part of the released acid and sulphate amount is mobilised and transported towards the environment. Parallely, the proportion of temporarily aerated and oxidizing iron disulphidic soil layers is reduced. When the re-increasing groundwater reaches a level above the groundwater level prior to the mining acitivity, no further release of acid and sulphate takes place. Therefore a reduction of the contamination of the groundwater by the products of iron disulphide oxidation is expected from this time onwards.

Besides the anthropogenic causes natural sources may trigger rarely a chemical attack potential for concrete structures (e.g. gypsum-rich soil layer in contact with groundwater). Since the locations of such gypsum deposits and their potential for sulphate release are widely known, the present attack potential can be evaluated with sufficient accuracy and considered for the evaluation of the concrete attack.

3.2 Attack potential of acidic and sulphatic groundwater in mining areas

Since iron disulphidic soils in mining regions have an enormous potential for the release of acid and sulphate, the resulting concrete aggressiveness of the groundwater influenced by such sources is of central relevance for this research project. In some regions a discharge of the aggressive oxidation products of iron disulphide has already been observed for the groundwater in the vicinity of mining areas. First forecast models suggest that a significant aggressive discharge is expected in these areas within the next years. Not least the re-rise of the groundwater level due to the cessation of mining activity is responsible for this development. The oxidation products are dissolved in the increasing groundwater and are transported in the direction of the groundwater flow. Consequently, for regions that have been unaffected by mining activity so far a more or less rapid increase in acidity and sulphate concentration in the groundwater can be expected. However, the acidification and sulphate

accumulation in soil and groundwater represents an attack potential for those structures only that are in terms of their geographical location and their depth of foundation under the influence of the aggressive media.

In regions with increased acid and sulphate concentrations in the groundwater most of the structures are not significantly subjected to a chemical attack if the groundwater level – after cessation of drainage for mining operations - is lower than the foundations depths of common structures (generally < 3 to 5 m below the ground surface). In such areas only structures with deep foundation e.g. tunnels or pile foundations may be in contact with the aggressive groundwater.

In regions where ground water is present just a few centimeter or meter below the ground surface (as often close to surface waters or mine dump [4]) the members of the structure in contact with the construction ground are exposed to a chemical attack. Although buildings with cellars are generally provided with protection measures against penetrating water, a durable protection against a chemical attack by the groundwater is not given.

A particularly high risk potential exists when the groundwater below a structure has been “artificially” decreased down to great depths by the drainage of adjacent mining operations for several years or decades. In such a case a groundwater level close to the ground surface may adjust when the draining will be ceased in the future. For the determination of the final groundwater level or the final water levels in mining lakes the water levels prior to mining influence were considered. In the meantime some buildings in the area of former cones of groundwater depression are known to have been built during the time of the mining operation without further regard to future groundwater re-rise or adequate protective measures. These buildings are now subjected to water penetration due to re-rise of groundwater in structural parts which are in contact with the ground [4]. Besides wetting problems in basements or underground structures a chemical attack can result from the aggressive groundwater which impairs the durability of the structure.

3.3 Measures for affected structures

In order to mitigate the aggressiveness of the groundwater and to minimise the degree of chemical attack on structures different measures have been discussed by experts and also implemented in practice for a long time. While some measures focus on reducing the rate of oxidation of iron disulphide in mining dumps, other measures concentrate on minimising the already released acid and sulphate loads. Furthermore, measures that keep the aggressive groundwater locally away from the affected structure may be efficient (e.g. by extensive groundwater drainage).

If the impact of aggressive groundwater cannot be prevented, at least the potential of chemical attack can diminished by shielding the structure against the groundwater flow using sheet piling or slotted walls. For new structures in areas with acidic and sulphatic groundwater foundations (e.g. pile foundations) in soil layers with groundwater should

generally be avoided. Instead, shallow foundations e.g. ground slab shall be preferred in order to reduce or completely prevent an attack of aggressive groundwater on concrete.

Besides measures that reduce the potential attack of the environment also methods to increase the structure resistance against a chemical attack are available. By means of the existing knowledge in concrete technology and defining adequate specifications to the components and the composition a high chemical resistance of concrete can be achieved. Such measures are certainly relevant primarily for new structures and feasible for existing structures for local repair or reinforcement of structural members only. In practice, the development of such high-performance concrete for use in concrete aggressive environment is currently being driven intensely.

Under very aggressive conditions concrete technological measures are insufficient for a durable protection of the structure or are not appropriate for existing buildings. In such cases constructive measures (e.g. seals, sacrificial concrete, veiled injection) may have technical and economic advantages.

3.4 Open questions

This state-of-the-art report deals with the mining impacts on the development of the groundwater quality in connection with the resulting attack potential on structures. The research for the necessary information revealed a low developed awareness of experts and the public for this problem. This observation probably results mainly from the hitherto small number of documented structural damages caused by a combined acid-sulphate attack. The reasons for the low extent of such damages is the still early stage of the gradual begin of acid and sulphate discharge from coal-mines. First prognoses state that this discharge will be intensified further within the next decades. Furthermore, the deterioration processes in affected strucutral members proceeds over a period of several years or decades. The damages are first perceived at a late stage when they are far advanced, since they occur preferably in structural members that are in contact with water or ground and are thus inaccessible.

The lack of awareness about the problem dealt in this research project became also apparent by the existing lack of knowledge concerning in the first instance the hydrological/hydrochemical aspects which are essential for the further assessment of the attack potential of acidic and sulphatic groundwater on structures.

These aspects include the longterm development of the groundwater quality (for a period of about 100 years) with regard to sulphate, pH and carbonic acid in the vicinity of mines. A reliable prognosis must consider the discharge from the mine dumps and the far-ranging effects of groundwater re-rise. For the latter the released and mobilised loads in former cones of groundwater depression and the flow conditions or directions of discharge that change with the re-rise of the groundwater are decisive. In contrast to the Lusatian and the Rhenish mining area no adequate prognosis models have been available for the mining

areas in Central Germany yet. Furthermore, there are no prognoses for the development of the pH-value in the groundwater or for the discharge of the oxidation products of iron disulphide in the regions of the cones of groundwater depression.

In order to assess the extent of the structures potentially affected by a chemical attack of contaminated groundwater, information about the current and future levels of the groundwater must be evaluated in combination with data about the foundation depths of the structures in affected regions. Here, protective measures that have been undertaken in individual cases must be considered.

The aim of future research work must be to develop concepts that allow to assess the potential extent of damage for concrete structures realistically and to develop adequate protection measures for new and existing structures. For this purpose a detailed knowledge about the deterioration mechanisms due to a combined acid and sulphate attack is required. First approaches are provided by the recent studies by SIEBERT [5].

On basis of the incomplete available information about the real groundwater conditions qualitative statements about the potential attack of groundwater influenced by mining on concrete structures was possible within the scope of this report (e.g. by assuming characteristic attack scenarios). Quantitative statements about the actually expected damage potential of such groundwaters require the elaboration of the above open questions. By means of this advanced basis of information the costs and risks of any rehabilitation measures for the groundwater and the remaining potential for structures can be assessed realistically. This report demonstrates that increased acid and sulphate loads in the groundwater in the regions of (former) mines is expected in future. Furthermore, the damage potential of structures in the affected areas increases by the re-rise of the groundwater. With regard to the changes of the groundwater quality, that has already been observed at the some places, an urgent need for research on this problem exists.

4 References

[1] Bellmann, F.; Erfurt, W.; Stark. J.: Gefährdungspotential der betonschädigenden Thaumasitbildung. Schriftenreihe des F.A. Finger-Instituts für Baustoffkunde, Bauhaus-Universität Weimar, 2010.

[2] Graupner, B.J.: Beitrag zur Prognose der Grundwasserbeschaffenheit im Lausitzer Bergbaurevier auf der Grundlage eines großräumigen prozessorientierten Geoinformationssystems. Dissertation, TU Bergakademie Freiberg, 2008.

[3] Lenk, S.: Grundwasserbeschaffenheit und hydrogeochemische Prozesse in Rheinischen Braunkohlen-Abraumkippen und in deren Abstrom. Dissertation, Lehrstuhl Angewandte Geologie, Ruhr-Universität Bochum, 2008.

[4] Richter, D.: Untersuchungen zu der Grundwasser-Beschaffenheitssituation in den Kippengebieten der ehemaligen Braunkohletagebaue Nordwestsachsens mit dem

Schwerpunkt auf diffusen Stoffeinträgen an Eisen, Sulfat und Säure. Facharbeit, Karl-Heine-Schule, Leipzig, 2007.

[5] Siebert, B.: Betonkorrosion infolge kombinierten Säure-Sulfat-Angriffs bei Oxidation von Eisendisulfiden im Baugrund. Dissertation, Lehrstuhl für Baufstofftechnik, Ruhr-Universität Bochum, 2009.