POST MINING HAZARD ASSESSMENT IN NORTH RHINE-WESTPHALIA (GERMANY) AT THE EXAMPLE OF THE AACHEN HARD COAL MINING DISTRICT

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ABSTRACT: *In North Rhine-Westphalia, large areas are affected by mining legacies endangering the ground surface and public safety. The problems arising and the current risk management are demonstrated at the example of the Aachen hard coal mining district. Hazards especially result from outcrops of coal seams mined at shallow depths and shafts whilst galleries usually seem to be rather unperilous due to their depth and small dimension. In this paper, the design of hazard zones and the assignment of hazard classes are described. Recent scientific developments related to the size of hazard areas are described and an outlook on future procedures is given.*

KEYWORDS: *Hazard, collapse feature, shallow mining, shaft, gallery.*

RESUME: *Des régions étendues de Rhénanie-du-Nord-Westphalie sont influées par des mines abandonnées présentant des risques pour la stabilité de la surface et la sécurité publique. La région houillière d'Aix-la-Chapelle est décrite, servant d'exemple pour ces problèmes et leur traitement. En particulier les mines proche de la surface et les puits sont plus dangereux que les galeries de taille plus faible et localisées à des profondeurs plus importante. Cet article précise le définition et l'affectation des classes de danger. Des développements scientifiques récents relatifs à l'étendue de la zone de danger sont décrits, ainsi que les améliorations futures prévues.*

MOTS-CLEFS: *Mines abandonnées, puits, galeries, zones de péril, classification des périls.*

1. Introduction

Large parts of North Rhine-Westphalia are affected by various mining activities. Most of these mining activities ceased meanwhile and left behind large post mining areas with hazards for public safety (see fig. 1). The problems arising in North Rhine-Westphalia from former mining activity and the current risk management of the mining authorities are demonstrated at the example of the hard coal mining district of Aachen (Aix-la-Chapelle).

Within this mining district lies one of the oldest coal mining areas in Europe, the so called "Wurmrevier" (mining district of the river Wurm) with an area of about 19 km² of which approximately 14 km² are populated densely. Here, below the cities of Herzogenrath and Würselen, the Carboniferous rock lies at shallow depths up to about 25 m and dewatering galleries were driven into the rock starting from the valley of the river "Wurm" (see fig. 2). Mining activity in this valley dates back to the 12th century or maybe even back to Roman times and mapped mining information is scarce.

The resulting hazard potentials are an important obstruction to land use planning. Before building permission is given, the general possibility of the existence of mining legacies is examined in a first desk study by the mining authorities. If mining legacies possibly could affect a site, then a more detailed second desk study and, if necessary, on-site investigations are performed by expert offices. Hazard zones around shafts and above coal seams mined at shallow depths have to be remediated according to the state of the art before building projects are permitted by the authorities. Existing buildings are not affected by any examination or remediation necessity.

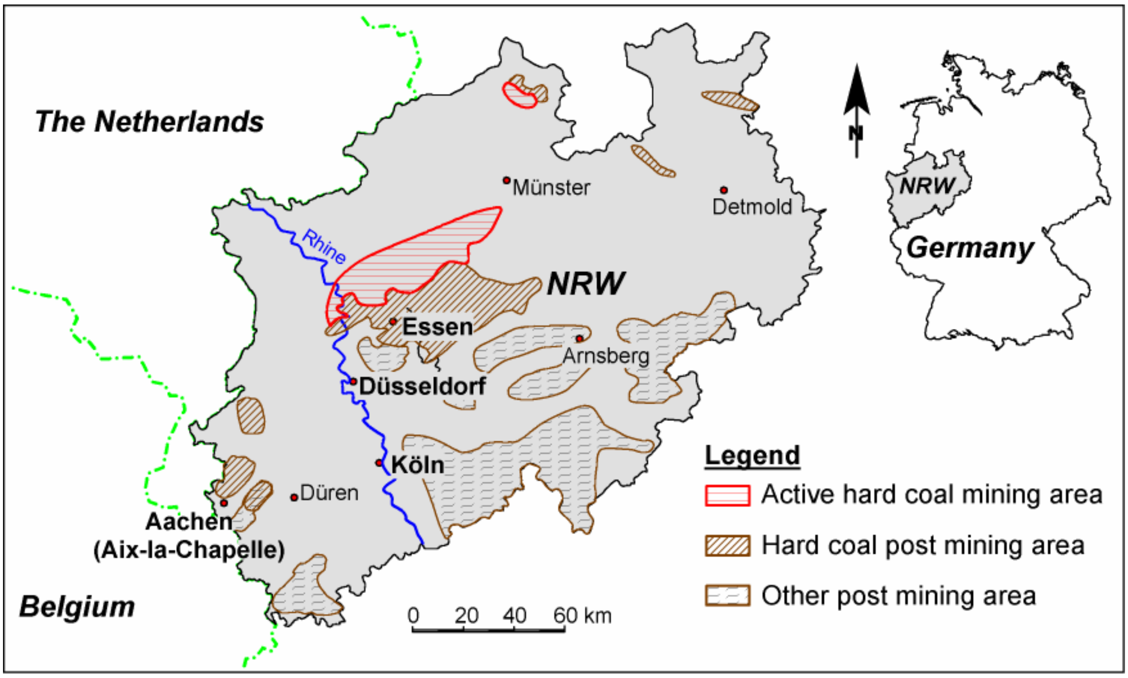

Figure 1: Mining areas in North Rhine-Westphalia (based on Welz, 2001).

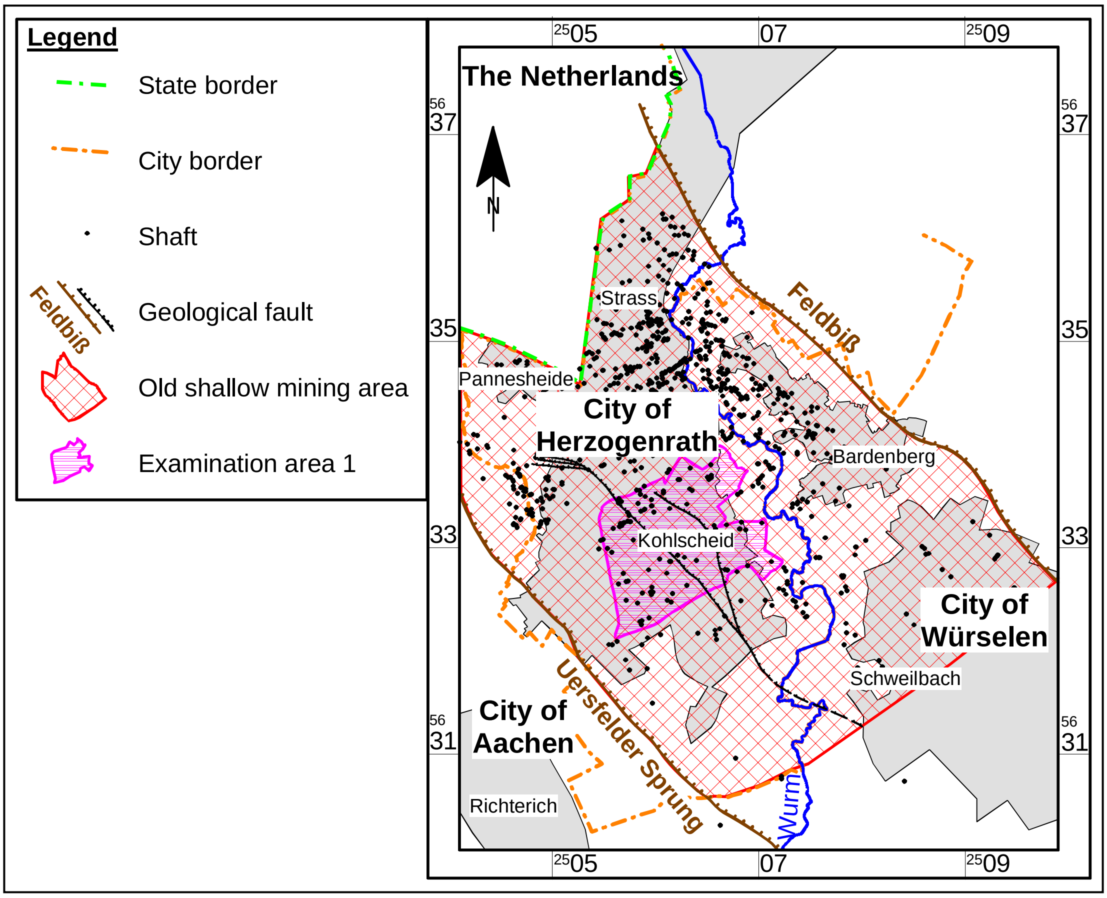

Figure 2: Area of shallow mining in the Aachen hard coal mining district.

2. Geology

2.1. Overburden

The overburden in the "Wurmrevier" consists of a thin layer of unconsolidated sediments of Quaternary and Tertiary age up to about 25 m thickness. A typical layer formation is a silty and clayey sand ("Lower Lintfort Formation") covered by Maas sand with gravel (sediments of the River "Maas") and loess loam on top. Towards the valley of the river Wurm, the overburden thickness decreases until the Carboniferous rock emerges at banking level.

2.2. Carboniferous rock

The Carboniferous rock of the Aachen mining district generally consists of sand-, silt- and claystones of Namur C to Westfal B age. The deposits are striking SW-NE and are folded quite intensively resulting in a broad variety of angles of dip of the coal seams. The enclosed coal seams have a spatial percentage of about 3 % of these sediments. Distinct geological faults strike NW-SE. East of the fault "Feldbiß" the surface of the Carboniferous rock lies significantly deeper than west of the fault. In the eastern part, mining activity did not start before the 20^{th} century when shafts were sunk to a depth of up to 800 m.

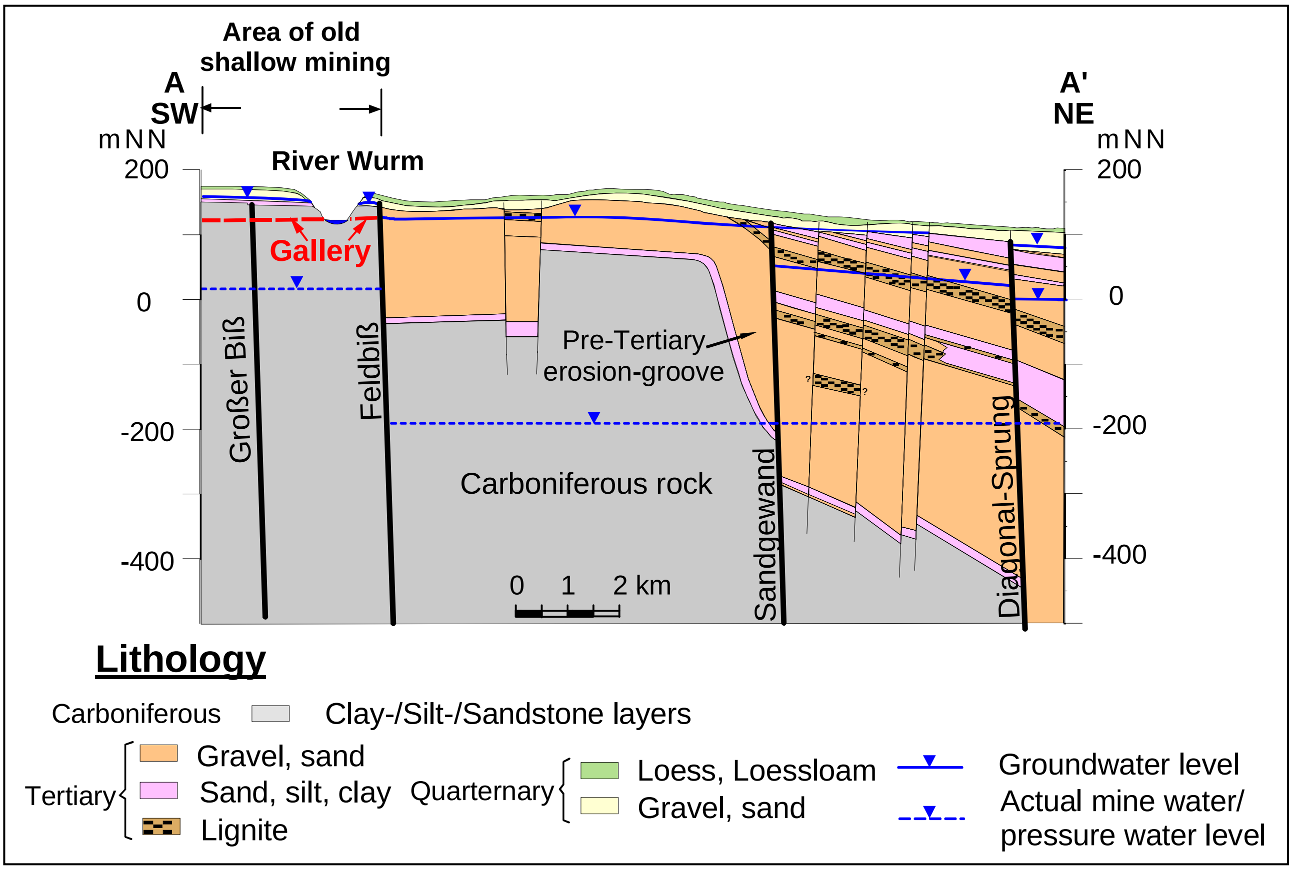

Figure 3: Geological-tectonical section of the Aachen hard coal mining district.

3. Hazard sources

Hazards within the Aachen hard coal mining district mainly result from collapse features above outcrops of dipping coal seams that have been mined at shallow depths (< 40 m) and abandoned shafts which often only have a partial and unstable filling or no filling at all. Even if the shafts have been filled, the filling material was not compacted densely. Moreover, abandoned shafts pose a risk of gas emissions.

The number of such abandoned shafts within the area of old mining activity west of the geological fault "Feldbiß" (s. fig. 3) is estimated to be more than 800. There is almost no information available on mining activity before around the year 1800 when during the French occupation mine mapping was intensified. From the year 1815 onwards Prussia kept up mapping the mining activities. Due to the very incomplete data on mining activity before 1800, a hazard of collapse features simply has to be assumed to be present along all workable coal seam outcrops.

Recent collapse feature events indicate that although the probability of collapse features may decrease with time, the principal possibility of such events is independent from time. There are a lot of long-term processes that can make a formerly stable void collapse, as e.g. decay of wooden supports, progressive failure, creep, weathering, hydraulic changes and stress redistribution.

Galleries commonly seem to pose no risk due to their depth and small dimension. Moreover, these galleries usually are partly filled up with sludge reducing the cavity volume. Rising mine water can lead to pollution of groundwater, river, lakes and soils due to its high contents of metals and salts, can make partial shaft fillings unstable by changing their cohesion and result in differential ground heave along faults. In the adjacent Erkelenz hard coal mining district, approximately 30 km north of Aachen, the mine water recovery caused a 'damage line' running approximately parallel to the Rurrand fault system. This 'damage line' has a length of about 10-12 km and differential heaves of up to 6 cm within a range of only 5 m. Until the end of 2004 damages occurred at 110 objects. Nine objects could not be repaired any more and had to be torn down (Heitfeld et al., 2004). Ground heave induced by the ongoing groundwater recovery is currently being researched within an international project group.

4. Hazard zonation

The current approach to mining legacies is linked to permission procedures for new buildings. Old existing infrastructure tended to avoid areas of former mining activity. Since such public knowledge of possibly dangerous areas is decreasing with time, it mainly is newly planned infrastructure that can be effected by mining legacies. Moreover, a large scale risk assessment and sanitation scheme for all existing buildings in NRW is an almost unfeasible task. Hence, only the most dangerous sources of hazards to existing buildings (i.e. deep shafts) are being secured by the mining authorities or the responsible mining company (if any) as a medium-term solution.

Since existing buildings are not affected by any legal constraint due to mining hazards, it is custom to only perform hazard assessments instead of risk assessments, which additionally to the possible event size and probability would respect the kind of land use and the danger to public safety related to that. The necessity of in-situ examinations and remediation measures is assessed based on a desk study and independently of the kind of building that is planned. It is assumed that either a new building is endangered by mining legacies, so that closer examination and in some cases remediation measures are needed or mining hazards to new buildings can be ruled out completely.

The desk study usually starts with an analysis of the literature on the mining history of the district and search for hints on former mining activity within old mine maps. The old mining ground maps are being scanned and georeferentiated and then overlapped computationally with modern housing maps. Street crossings and old houses serve as weighted benchmarks. The findings thereafter are assessed as described below.

4.1. Coal seam outcrops

For assessing the hazard of collapses at banking level above outcrops of coal seams mined at a shallow depth, three hazard classes are being distinguished depending on the evidence of former mining activity, the thickness and the angle of dip of the different coal seams. It thereby is assumed that cavities show a better long term stability in seams with high angels of dip, ("steep flanks", $\alpha > 36°$) than in such dipping with lower angles ("plane flanks", $\alpha \leq 36°$). This is due to the higher vertical compaction forces acting on cavities in seams with low angles of dip making them less stable and collapse sooner. Since the main mining activity at shallow depths ceased more than 200 years ago, most surface near cavities in coal seams with a low angle of dip have collapsed meanwhile and pose no risk to the surface any more. Hence, coal seams with high angles of dip are deemed to be more hazardous today. This assumption was verified by extensive site investigations (borings) within the Aachen hard coal mining district.

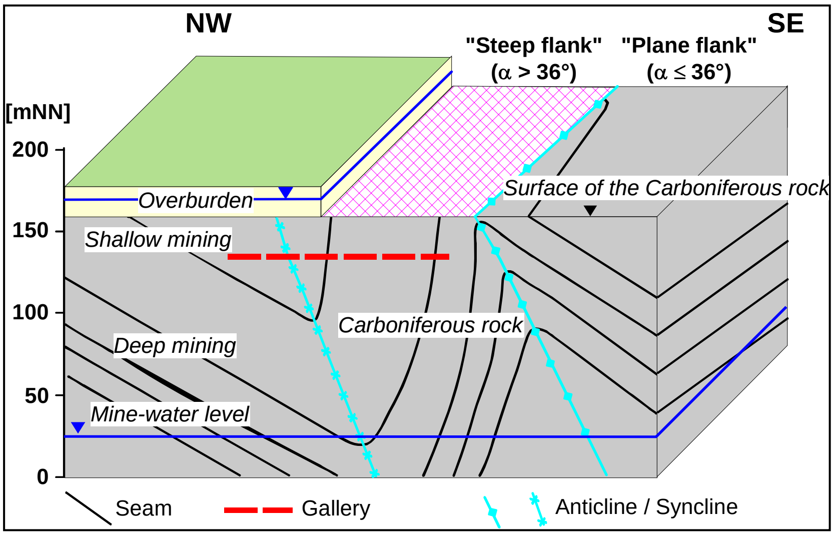

Figure 4: Model of the hard coal deposit of the "Wurmrevier".

This conception led to the following assignment criteria for the hazard class assessment above coal seam outcrops:

Table 1: Hazard class assessment above coal seam outcrops

Hazard class 1	High probability of collapse features / subsidence (evident mining activity, coal seam dipping > 36°)
Hazard class 2	Probability of collapse features / subsidence (supposed mining activity, coal seam dipping ≤ 36°)
Hazard class 3	Low probability of collapse features (mining activity can not be ruled out)
	Remediated areas / areas with proven stability

On-site investigations are necessary before building is permitted, if the hazard classes 1 or 2 are assigned. In case hazard class 3 is assigned, no on-site investigations are needed for nonsensitive buildings as e.g. housing. In case of power plants, chemical facilities etc. on site-investigations are necessary for geotechnical category 3 according to the Eurocode 7.

The width of the possibly affected area perpendicular to the strike of the coal seam outcrop is assessed based on alignment charts (Hollmann & Nürenberg, 1972), giving the endangered area on the surface of the Carboniferous rock (fig. 5). The width of the coal seam outcrop and in most cases an uncertainty related to the location of the coal seam in an order of magnitude of about 10 - 20 m has to be taken into account additionally.

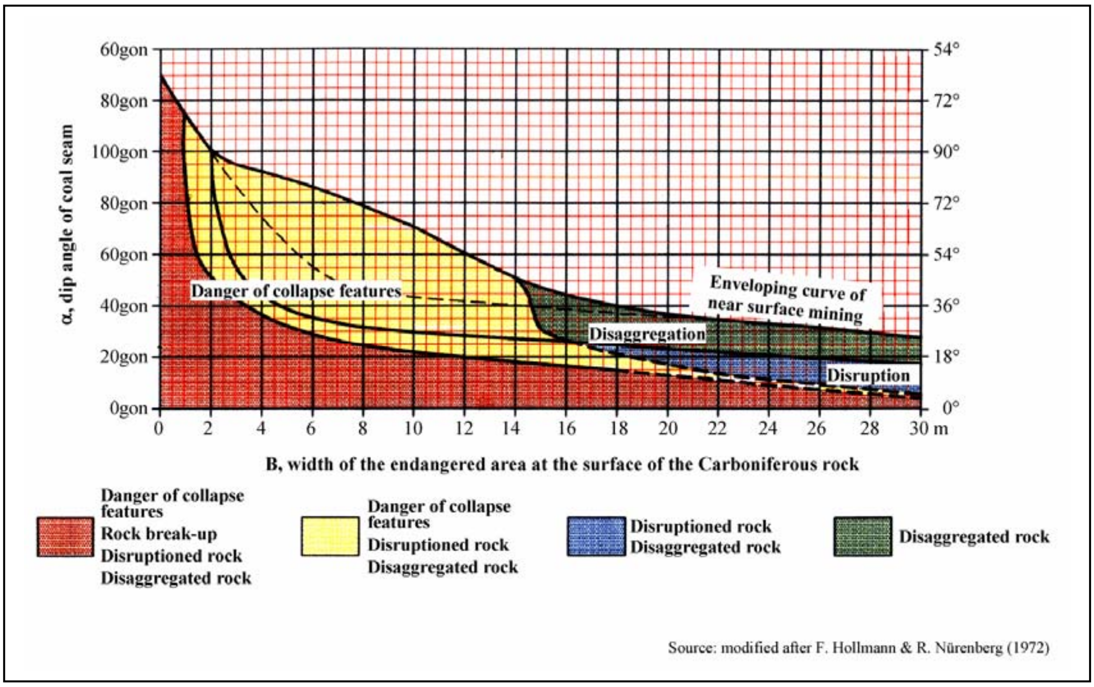

Figure 5: Width of the endangered area at the surface of the Carboniferous rock.

These hazard areas at the surface of the Carboniferous rocks then are projected towards the ground surface using a generalized angle of break of 45° within the overburden giving the width of the hazard area at banking level (fig. 6). In fact, the observed collapse features within the "Wurmrevier" show steeper slopes (also see chap. 5). A relatively low slope angle complying with the angle of friction of the soil does not develop because the collapse features usually are filled and remediated swiftly after they occurred.

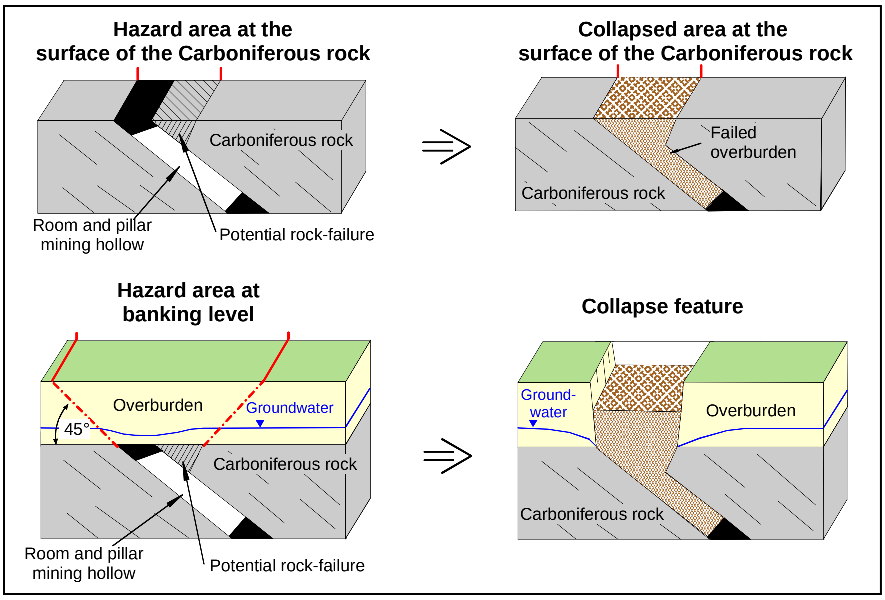

Figure 6: Hazard of collapse features above coal seam outcrops.

4.2. Shafts

The diameter of areas around unsafe shafts currently is assessed as the sum of the shaft diameter, twice the thickness of the shaft wall, twice a safety distance of 1,5 m (for disaggregation of the surrounding rock) and twice the level difference between the surface of the Carboniferous rock and banking level, also assuming an angle of break of 45° within the overburden (see fig. 7). Usually the exact location of a shaft is unknown and an uncertainty of about 10 - 20 m is to be considered, too.

No hazard classes are being distinguished within the collapse hazard zone of a shaft where building generally is not permitted as long as the shaft was not secured.

Gas hazard zones with a diameter of 40 m also are assigned to each shaft. Within this area buildings must be protected against gas using granular fill venting media and membranes. Pipes in which gas might accumulate are to be sealed.

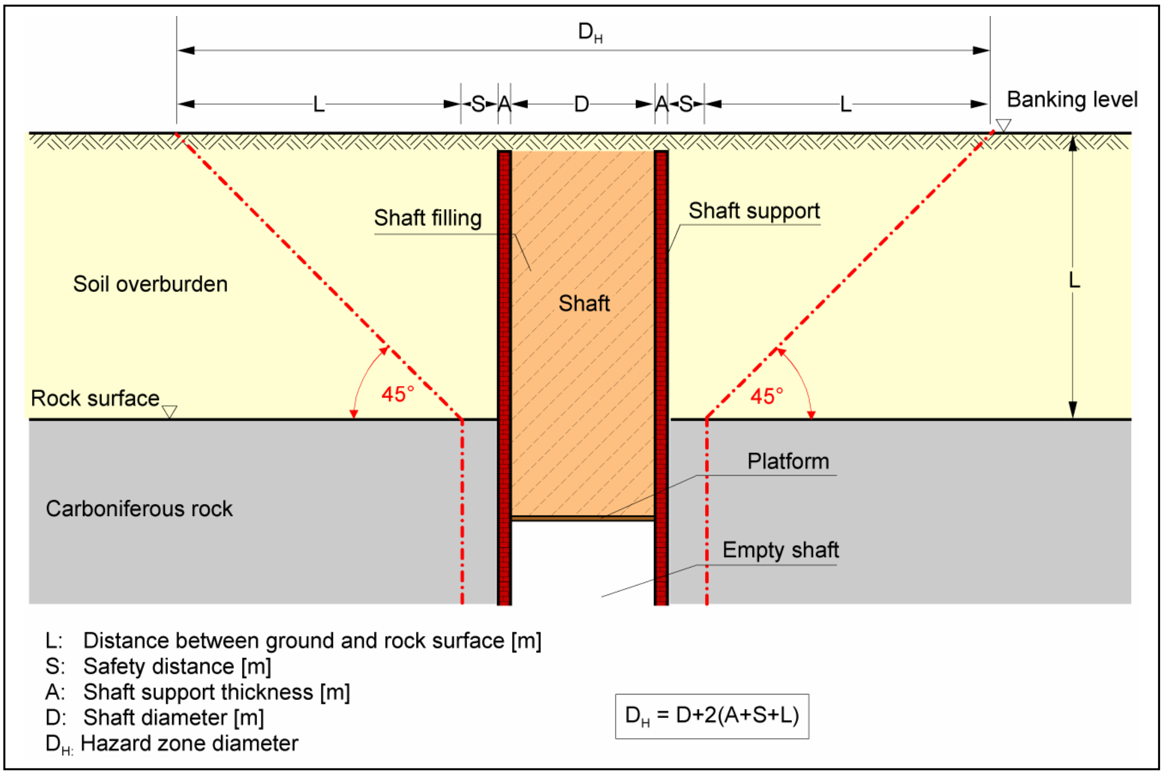

Figure 7: Shaft hazard zone.

4.3. Example of a medium scale hazard assessment ("examination area 1")

Lead by the North Rhine-Westphalian higher mining authority (Bezirksregierung Arnsberg), a first medium-scale hazard assessment for a densely populated area of approximately 1,8 km² was performed by the post mining working group of the Aachen mining district in 2002 (see fig. 2). Next to other members, this working group consisted of the responsible lower mining authority (Bergamt Düren), the local mining company (EBV AG), the geological survey (GD) and the IHS. Based on an intensive analysis of old mining ground plans and sections as well as geological-hydrogeological maps, surface projections of the deposits were elaborated and shallow mine workings and shafts were documented. Then a hazard map (see fig. 8) was worked out for coal seam outcrops using the hazard classes shown in table 1 and the chart of Hollmann & Nürenberg (1972), shown in fig. 5. This map shows hazard zones at the surface of the Carboniferous rock. In order to gain hazard zones at banking level an angle of break of 45° within the overburden as well as coal seam location uncertainties (usually about ± 10 - 20 m) have to be taken into account additionally. In order to minimize the hazard zones at banking level for specific projects, these coal seam location uncertainties can be minimized by borings.

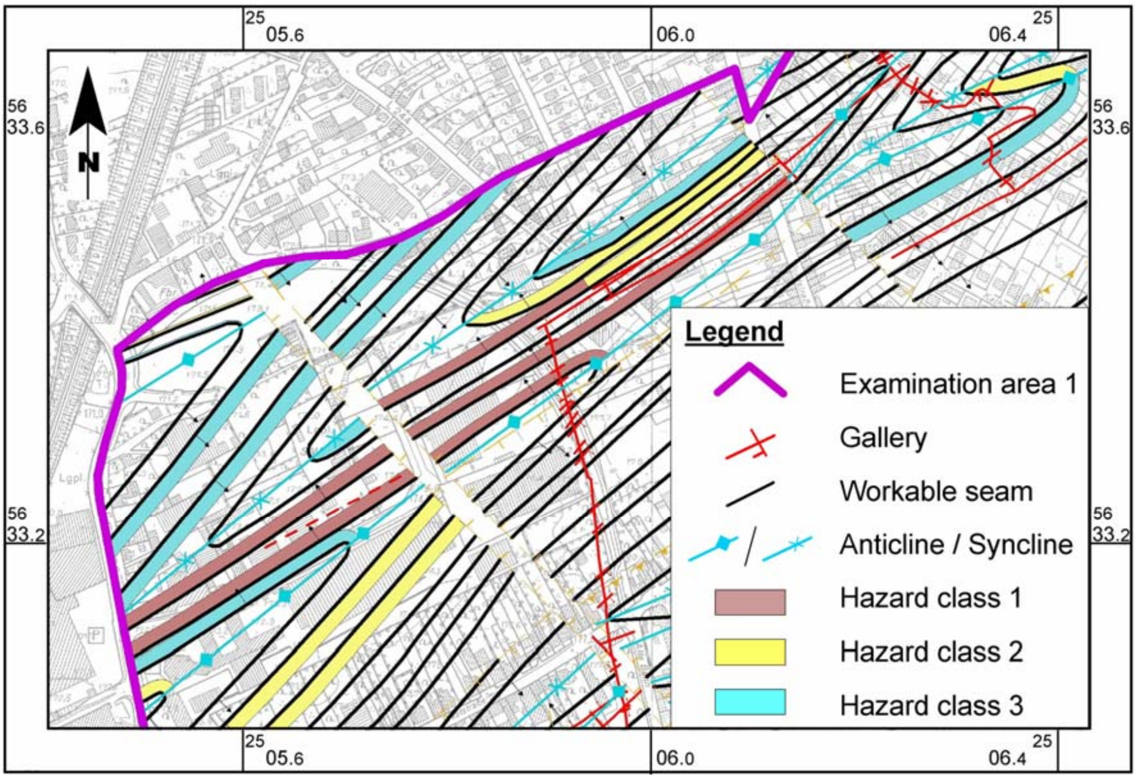

Figure 8: Detail of the coal seam outcrop hazard map at the surface of the Carboniferous rock for examination area 1

Another hazard map shows shaft hazard zones at banking level based on the design method for a shaft hazard zone described above (see fig. 7). These hazard maps now are basis for any building permission process within the examination area 1.

The local authorities of the city of Herzogenrath and the mining authorities are planning a large scale hazard assessment for the complete “Wurmrevier” within the next years. The results are meant to ease local town planning and to reduce the fear to invest in this area.

5. Outlook

The method currently used in North Rhine-Westphalia for designing hazard zones above coal seam outcrops assumes an angle of break of 45° within the soil overburden. This assumption does not take into account any soil mechanical properties of the different types of soil of the overburden.

First results of a PhD study (Mainz, see Heitfeld et al., 2005) indicate that a significant reduction of hazard zones in the Aachen “Wurmrevier” is possible considering the geotechnical properties of the overburden. Within the study collapse features where investigated using borings, penetration tests and extensive laboratory works. The study revealed, that the generalized angle of break of 45° within the overburden leads to significantly oversized hazard zones.

The on-site investigations show that the collapse process can be partitioned into single process phases with different collapse geometries depending on the soil parameters (see fig. 9). This led to a special local collapse feature model for the “Wurmrevier”.

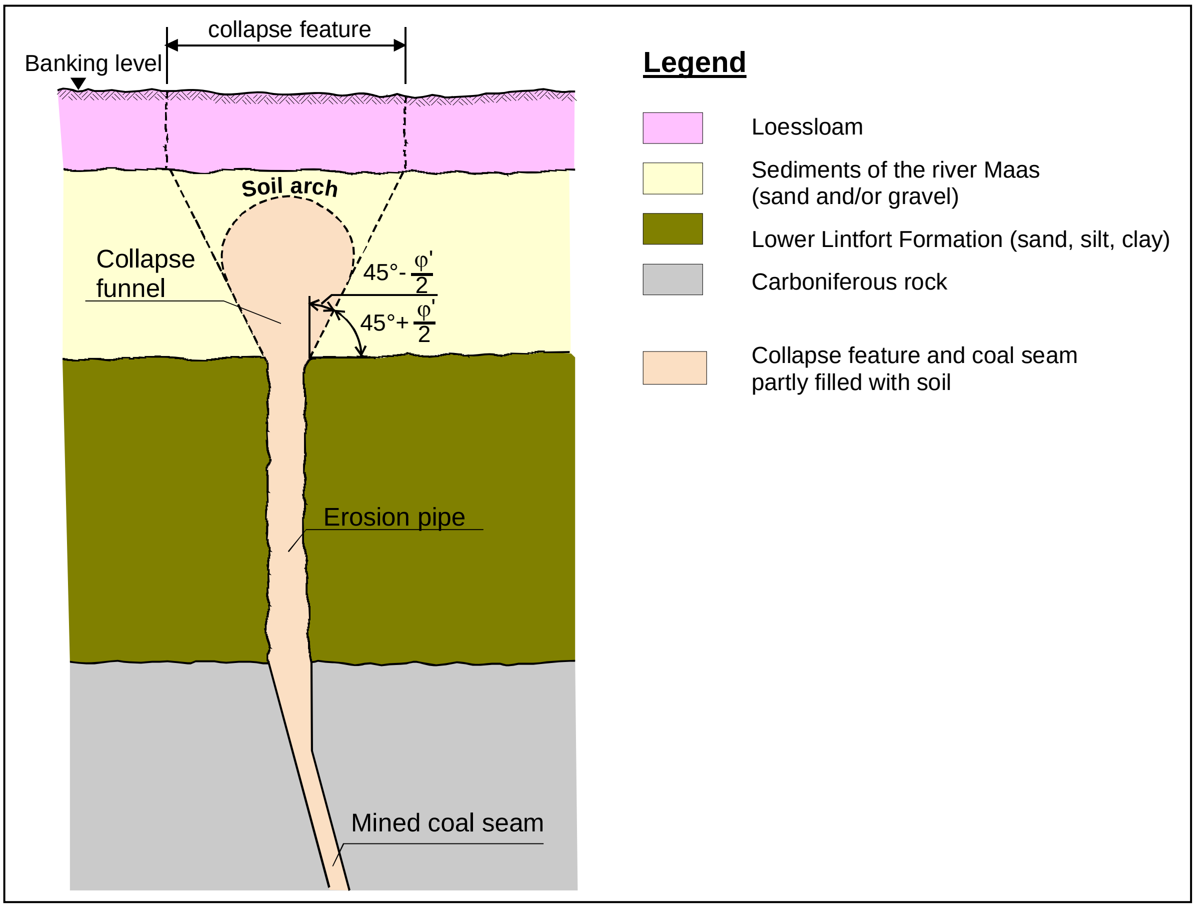

Figure 9: Collapse feature model.

Within the silty and clayey sand of the Lower Lintfort Formation no growth of the collapse towards the sides was observed. The collapse feature develops as a vertical pipe. Fig. 10 shows two stress circles for typically limiting depths of the “Lower Lintfort Formation”. None of the stress circles touches the critical state line of this cohesive soil. The Mohr-Coulomb failure criterion is not fulfilled. The upward movement of the cavity within this cohesive soil layer hence is a pure vertical erosion process.

As soon as the collapse process reaches the sand and/or gravel of the sediments of the river Maas, the soil properties change and cohesion drops. Now the stress circles for typically limiting depths, outlined in fig. 11, both touch the critical state line. Hence the Mohr-Coulomb failure criterion is fulfilled. The soil shears with an angle of break of $\beta = 45° + \varphi'/2$ resulting in a funnel shaped part of the collapse feature.

When the cavity gets too close to banking level, the soil arch above the cavity becomes unstable due to insufficient thickness and in the first instance collapses with vertical shear planes within the cohesive loess loam following the direction of gravity forces (also see Penzel, 1980).

Hence, the width of the hazard zone W_{Hazard} at banking level above coal seam outcrops in the old mining district “Wurmrevier” comprises the width of the hazard zone at the top of the Carboniferous rock and the horizontal growth within the noncohesive sediments of the river Maas along an angle of break of $\beta = 45° + \varphi'/2$.

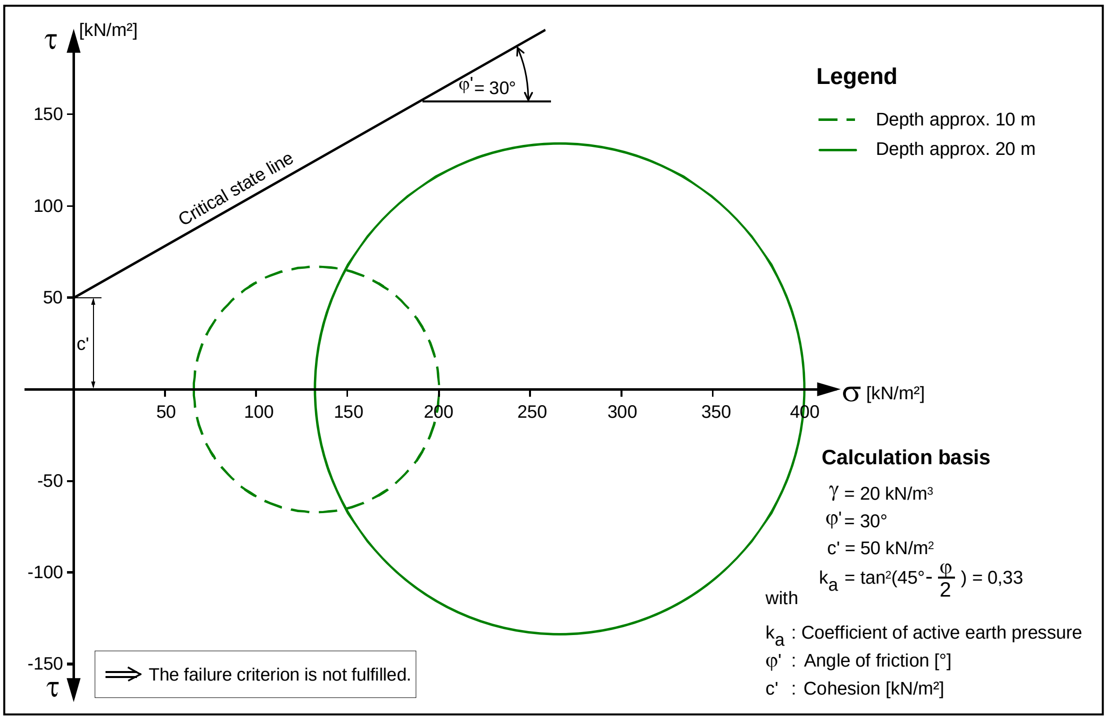

Figure 10: Mohr-Coulomb failure criterion for the Lower Lintfort Formation.

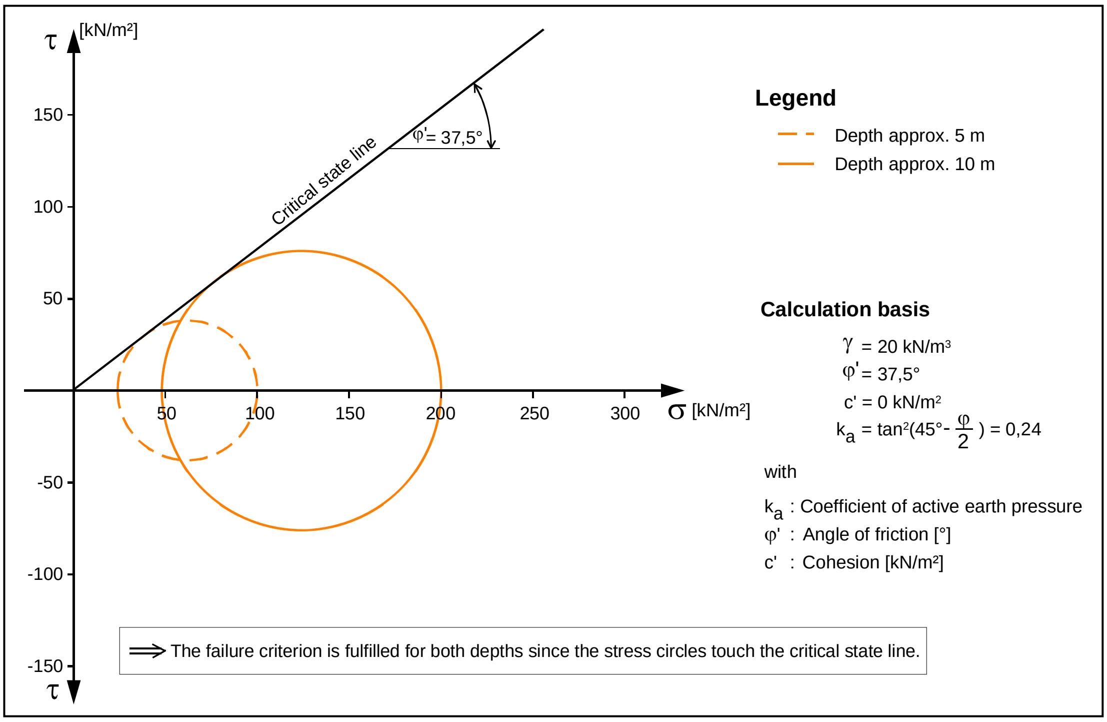

Figure 11: Mohr-Coulomb failure criterion for the Sediments of the river Maas.

In the proposed model a safety allowance for variation of the model parameters was chosen with η equal to 1,1 times the thickness of the sediments of the river Maas T_{MS} since these sediments are crucial to the prognosis of hazard zones when using the proposed model. The formula for the width of the hazard zone at banking level then is:

$$W_{Hazard} = 2*\eta * T_{MS} * \tan(45°-\varphi'/2) + W_{LLF}$$

The hazard zone width at the surface of the Carboniferous usually is assessed according to the chart of Hollmann & Nürenberg (1972, see fig. 5) plus the horizontal width of the coal seam outcrop. The width of the collapse feature within the Lower Lintfort Formation, respectively the zone within the Lower Lintfort Formation where the erosi on pipe might occur, W_{LLF} is assumed to be equal to this maximum hazard zone width at the surface of the Carboniferous. Based on the performed laboratory works, the average angle of friction φ' of the sediments of the river Maas can be assumed to be at least φ' = 35°.

The formula for the hazard zone at banking level then simplifies:

$$W_{Hazard} = 1{,}15 * T_{MS} + W_{LLF}$$

Backward analysis of real collapse features within the "Wurmrevier" showed good conformance of the model results with the real collapse feature dimensions. The model described above *can only be applied* to the "Wurmrevier" of Aachen and to the very special soil layer constellation and soil characteristics described above. These have to be verified by investigations for every single project.

When using this model, an allowance for the uncertainty of the coal seam location and the minimum distance of the planned building to the collapse feature should be taken into account additionally. This allowance is to be specified in accordance with the responsible governmental authorities.

Furthermore it has to be checked that a cohesive layer of a sufficient shear strength (φ' = 30°, c' ≥ 50 kN/m²) without major cohesion less sand layers exists, enabling a stable erosion pipe within this formation. Adequate horizontal in-situ stresses, corresponding to shallow depths, are provided. Also a sufficiently homogeneous and cohesive loessloam top layer is a prerequisite.

The transferability of the proposed model to the collapse process of shafts and other soil layer conditions within the Aachen hard coal mining district is currently being researched. The transferability of this model to other areas poses a future scientific task.

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