International Journal of Mining Science and Technology 28 (2018) 79–83

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Use of the area of main influence to fix a relevant boundary for mining damages in Germany

Denise Müller *, Axel Preusse

Faculty of Georesources and Materials Engineering, Institute for Mine Surveying, Mining Subsidence Engineering and Geophysics in Mining, RWTH Aachen University, Aachen 52072, Germany

ARTICLE INFO

Article history:
Received 10 June 2017
Received in revised form 22 August 2017
Accepted 19 October 2017
Available online 10 January 2018

Keywords:
Ground movements
Area of main influence
Boundary for mining damages
Subsidence-area mining regulation
Subsidence detection
Modeling above caverns

ABSTRACT

In 2010, the fracking discussion in Germany caused a number of changes in German law, which came into force in 2016. Especially the production of gas had to be regulated. With the legislation amendment, the *Subsidence-Area Mining Regulation* has been revised, too. The changes expand the compensation of mining damages, especially to the extraction with drilling from the surface and underground storage. Although the *Subsidence-Area Mining Regulation* has been revised, the area of main influence (subsidence of 10 cm) remains to determine a relevant boundary for mining damages. The determination and prediction of this boundary above caverns are presented in this paper. In addition, further elements of ground movements and their relevance to mine damages are analyzed. The usage of the area of main influence to fix a relevant boundary for mining damages does not correspond to the relevant elements of ground movements. A limit for differences in subsidence (tilt) or horizontal changes in length should be preferred to describe the relevance of mining damages on buildings. Furthermore, this paper outlines the meaning of using the area of main influence to fix a relevant boundary for mining damages.

1. Introduction

The *Federal Mining Act* forms the central legal standard to cover subsidence in Germany. The mining authority refers to the following regulations: the *Subsidence-Area Mining Regulation*, the *Mine-Surveyor Mining Regulation*, and the *Deep-Drilling Regulation* [1,2].

Until the law, which generated changes in the *Federal Mining Act* and the *Subsidence-Area Mining Regulation*, had passed in 2016, the applicability of the *Mining Subsidence Assumption* was controversial regarding extraction by drilling from surface and caverns. The *Subsidence-Area Mining Regulation* did not consider either of them [3].

The *Mining Subsidence Assumption* contributes to support landowners within the area of main influence, if the landowner wants to claim damages. This support is called reversal of burden of proof. If the affected landowner can prove that: his property is inside the area of main influence, damage may be induced by mining, and damage is caused by ground movements (due to subsidence, extension, compression, soil tear, vibration), it is assumed that the damage is caused by the mining operation. In this particular case, the mining company has to prove that the damages are not mining-induced. Outside the area of main influence and without this regulation, the landowner has to prove that the damage is mining-related [4].

According to the *Federal Mining Act*, the *Subsidence-Area Mining Regulation* specifies the way to determine the mining-influenced area.

A statement of why the area of main influence remains to determine a relevant boundary for mining damages in Germany can be taken by the reasoning of the law. It is referred in the original regulation [3]. The area of main influence was chosen for the "reversal of burden of proof" to support the landowner because there are no damages expected outside of this area. In addition, it was proven by measurements that the damage-relevant element tilt does not exceed 2 mm/m outside the area of main influence. For this reason, there was no need to use a further value to determine the relevance to mining damages [5]. This statement and its consequences are considered in this paper.

2. Amended subsidence-area mining regulation

On the one hand, the "*Subsidence-Area Mining Regulation*" covers an area with regard to the application of the "*Mining Subsidence Assumption*." On the other hand, the approval of operating plans are also covered by this regulation [2].

* Corresponding author.
E-mail address: mueller@ifm.rwth-aachen.de (D. Müller).

https://doi.org/10.1016/j.ijmst.2017.10.004
2095-2686/

With regard to the area of the *Mining Subsidence Assumption*, there is a need to determine the area of main influence. This area includes subsidence up to 10 cm (Fig. 1). The regulation contains an attachment with listed angles of main influences () for a couple of mining branches. In this case, the area of main influence should be constructed using the given angle. If the attachment of the regulation does not include the mining branch, or the area of main influence cannot be determined by an angle, or the predicted area of main influence does no correspond to the real area of main influence to be identified individually. The attachment does not consider extraction by drilling from surface nor caverns. In the special case of vibration, the area of main influence has to be determined by seismological services and not by a mine surveyor [2].

For "special plants" (such as sluices and bridges), subsidence up to the subsidence border is considered. In this case, the area (of mining subsidence) is constructed with the angle of draw () (Fig. 1). This regulation is less important for the "Mining Subsidence Assumption" [5].

For the approval of operation plans, the mining company has to determine the subsidence up to the subsidence border by use of the angle of draw, as well. The subsidence border is defined by the area in which subsidence can be measured. There is no list of angles of draw given in this regulation [6].

In case of an underground cavern, Fig. 1 shows the angle of main influence and the angle of draw corresponding to their definition in the *Subsidence-Area Mining Regulation*. The angles refer to the deepest point of the exploration in depth and the area of 10 cm subsidence or the subsidence border on top of the surface. From the author's point of view, the deepest point of a cavern should be assumed to be where solution mining starts. Subsidence can be measured significantly up to 5 mm [7]. For this reason, the current definition of the subsidence border to determine the angle of draw is expected to contain subsidence up to 5 mm, from the author's point of view. The understanding of the angle of draw in Germany, especially with regard to the regulations, differs from the angle of draw in the USA [1]. In Germany, the angle of main influence and the angle of draw are measured in gon, with 400 gon being a full circle.

3. Ground movements

The vertical and horizontal convergence of a cavern induces subsidence. The convergence depends on several parameters, such as the height and the geometry of a cavern, the pressure difference between the formation and the medium that is stored, the temperature, as well as the type of rock salt [8]. The subsidence of each cavern superposes to a total subsidence. The subsidence trough is flat and reaches some decimeters after an operating time of 10 to 15 years. After a while, it may reach a few meters [9].

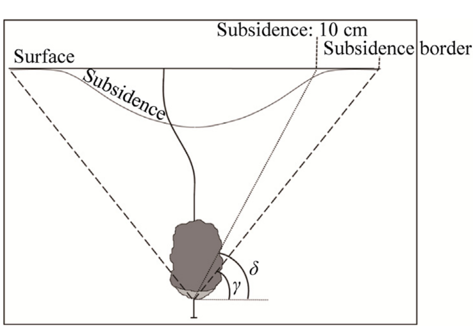

Fig. 1. Mining influenced areas corresponding to the *Subsidence-Area Mining Regulation* for underground caverns.

3.1. Two examples for subsidence troughs above caverns

In 2015, the number of gas-stored caverns in Germany amounted to 260 in total [10]. The greatest gas-storage cavern field of the world is located in North Rhine-Westphalia in the northwestern part of the Münsterland region [11]. In 2015, 76 caverns were stored with gas. The working gas volume of the caverns amounts to more than 3600 Mio·m^3. In addition, salt is extracted in more than 25 caverns; oil and helium (since 2016) are stored subordinately [10–12]. Monitoring shows that the highest convergence rates can be expected by the storage of gas (0.8%–1.6%) [11]. In 2013, the maximum subsidence was about 71 cm after an operation time of 41 years (gas storage since 1978). The increase of the subsidence trough amounts to 3 cm per year at the center of the trough [11,13].

In comparison to this, the gas-storage cavern field "Empelde" which is located in Lower Saxony consists of four gas-stored caverns with a working gas volume in amount of 136 Mio·m^3 [10]. The maximum subsidence amounts to 4.4 cm (2009) after an operation time by approximately 31 years (gas storage since 1981) [14]. As this example shows, subsidence of 10 cm is not reached by every cavern field.

Due to subsidence, other components of ground movements appear. As Table 1 shows, ground movements can be separated into vertical and horizontal components. The corresponding symbols and units are given, as well.

After finishing subsidence, only the point in the center of the subsidence trough is located underneath its original location. All other points of the subsidence trough moved in the direction of the focal point of working. The spatial displacement vector is more or less slanted towards the point of working, depending on the location of the point [9].

The graphical representation of the subsidence underneath its original location, without regard to displacement, shows a picture of the subsidence curve. The first derivative gives the tilt curve. The maximum tilt appears at the point of inflection of the subsidence curve. The second derivative gives the curvature curve. The curvature is convex close to the subsidence border and concave above the mining area. The curve has four maxima [9].

Displacement and changes in length are horizontal components. The graphical representation of the displacement can be realized by drawing the determined displacement perpendicular above the center of the point distances. The difference of the displacement of two points yields the changes in length (extension or compression). Above the mining area, changes in length appear as compression, whereas, close to the subsidence border, they appear as extension [9].

Fig. 2 shows the graphical representation of ground movements. Within the German standard for strata and ground movements (DIN 21,917), the ground movements shown are referring to seam mining. On the left hand side, the vertical components are shown, while, on the right hand side, the horizontal components of ground movements are shown.

Table 1
Elements of ground movements, modified according to Kratzsch [9].

Vertical component	Horizontal component
Subsidence v_z (mm)	Displacement v_x, v_y, v_{xy} (mm)
Maximum subsidence $v_{z\ \mathrm{Max}}$ (mm)	Maximum displacement $v_{xy\ \mathrm{Max}}$ (mm)
Tilt v'_z (mm/m)	Changes in length ± Δs (mm)
Curvature v''_z (1/m)	Extension $+\varepsilon$ (mm/m)
Radius of curvature ρ_z (m)	Compression $-\varepsilon$ (mm/m)

Note: Further components includes the subsidence factor, mined seam thickness, factor of main influence, and time factor.