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Surface movement above old coal longwalls after mine closure

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ABSTRACT

Although most subsidence occurs in the months and years after mining by the longwall method, surface movement is still occurring many decades after the mining. The aim of the study is to quantify the long term behavior. Satellite data (radar-interferometry) were analyzed to study an area of about 2 km^2 during the 18 years following the closure of the underground infrastructure and the flooding of the underground workings and rock mass. It was observed that, on average, a residual downward movement took place till 7–12 years after the closure, followed by a clear uplift. However, the first signs of an uplift occurred in certain sub-areas 3–4 years after the closure. Zones within the area studied were identified with either larger or smaller movements. However, the spatial variation of the surface subsidence or uplift could not be directly explained by the characteristics of mining.

1. Introduction

The longwall mining method always induces surface movements, which are caused by collapses in the mined out areas (goaf). The amount of surface movement is influenced by a large number of parameters, including the number and thickness of the coal seams that have been mined, the depth of the seam(s), the inclination of the seam(s), the surface topography, the composition of the overburden, and the presence of faults [1–4]. The rule-of-thumb method often is used to estimate the maximum subsidence as a function of the thickness of the coal seam. This method results in different values for various coal basins. In general, these values range from 40% to 90% of the total mining height [4,5]. In the coal basin that we studied, i.e., the Campine Basin in northeast Belgium, values of 80% to 90% normally are used. However, these values only give a very rough estimate of the maximum subsidence, i.e., the subsidence that can be expected in the middle above a longwall panel or above a fully mined-out area, i.e., an area without any barriers or unmined zones. The value also is valid only in the case in which there are no major faults.

In the central part above a longwall panel or above a fully mined-out area, it often is assumed that the new surface remains parallel to the original topography, so that no differential displacements occur. Around the edges of a mined area, the subsidence evolves from the maximum value in the central part to a subsidence of nearly zero at a certain distance away from the mined-out area. Thus, the subsidence results in a curvature of the new surface, as illustrated in Fig. 1. For a single panel, it can be assumed that a trough is formed [6,7]. This leads to differential vertical displacements and to horizontal displacements (horizontal strain in tension and in compression) around the edges. Generally, it is assumed that damage to the infrastructure occurs mainly in such areas, i.e., where large differential vertical displacements and large horizontal strain exist. Again, the rule-of-thumb method often is used to describe the typical angle of draw [2]. This angle is defined as the angle made by drawing a vertical from the base of the edge of the longwall panel to the point of no surface subsidence (Fig. 1). The angles vary from 20° to 60° in different coal basins and for different strata. The value of the angle is influenced strongly by what one considers to be 'no subsidence'. In the past, a cut-off of 20 mm often was assumed [2]. In the coal basin that we studied, recent research indicated that an angle in the range of 55° to 60° could be expected, but a value of 45° often has been used in the past.

Apart from the typical values used for the maximum subsidence and the angle of draw, different values are used to describe when most of the subsidence has occurred. This time period varies mostly between 2 and 5 years [3,8–10]. However, one should not forget that there is still a subsidence rate after this period, but it will be less than the rate measured immediately after mining (see additional results later in the paper).

Most of the concepts that we have described briefly above are based on observations and research that were conducted in the 1960s and 1970s [11]. A critical evaluation shows that part of the observations and conclusions were typical for the case in which only a single panel was mined. So, much less attention is given

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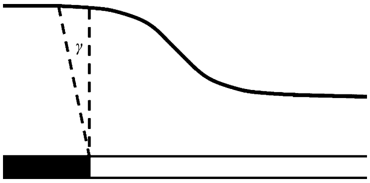

Fig. 1. Schematic drawing of surface subsidence above edge of longwall panel and angle of draw γ (not at scale).

to the interaction between panels in the same seam or in different seams. The frequency of measurements (in space as well as in time) mostly was small. An extensive survey over an entire basin typically was conducted once a year or every 2–5 years, if at all, and the distance between the observation points was in the range of 100 m rather than the range of 1–10 m. Also, there was no back-up with numerical modeling at that time to better quantify the effects of the various parameters. As a result, the typical or average behavior within a coal basin was used. To translate the observations into a theoretical model, smooth curves (as function of time and/or space) were used. For example, in that time period, exponential and logarithmic laws were popular because they made the calculations easier. The low frequency of measurements also impeded the development of more complex models. By averaging and smoothing the observation curves, a certain amount of detail is lost. A final, but no less relevant, aspect was the accuracy of measuring small movements. Often, the subsidence was considered to have stopped if a surface movement of less than 20 mm was observed between two measurements [2].

Although these rules of thumbs and theoretical models still have value today and still are being applied in order to estimate approximately what will happen, they also have limitations and do not provide the full picture. One should be aware that they only provide the global background picture of subsidence and that they focus on the direct impact of mining during its lifetime. Hence, to study surface movements after the closure of a coal mine, new insights are needed [12–14]. This paper is focused on this issue. The main aim of the research is to quantify the residual subsidence over the long term and the uplift of the surface area after flooding the underground workings following their closure. Since the 1990s, satellite data have been used to study surface movements, and almost any area of interest can be studied using approximate monthly measurements that are available with a dense measuring grid [15–18]. (In Section 3, further information is provided.) The objective of this research was to study a relatively small area of about 2 km^2 (1775 m from east-west by 1100 m north-south) above an old coal mine after closure, considering in detail any vertical movement. By a better quantification of the surface movements in the long term, one creates the necessary knowledge to start estimating this behavior by analytical and numerical methods.

2. Area studied

In this research, we studied part of the surface area above the underground coal mine of Houthalen, Belgium. Coal production in this mine began in 1939, and the mine was merged (and connected underground) in 1964 with the Zolder Coal Mine, which is situated to the West. Both mines were closed in 1992. The area in which the surface movement was studied in detail is situated between latitude 51.020°N and 51.030°N and between longitude 5.355°E and 5.380°E. Fig. 2 shows all longwall panels superimposed, i.e., the ones in the area that was studied, which is indicated by dashed lines but also in the area immediately surrounding this area. Fig. 2 covers the area between latitude 51.01°N and 51.04°N and between longitude 5.34°E and 5.40°E.

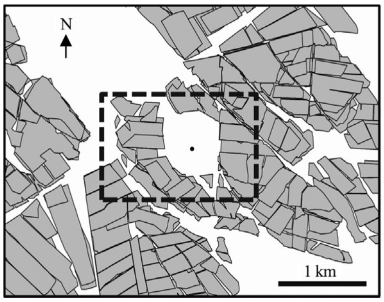

Fig. 2. Mined longwall panels (in grey) in the area between Latitude 51.01°N and 51.04°N, and Longitude 5.34°E and 5.40°E, and indication of studied area in this paper.

So, within the area that we studied, numerous longwall panels in different seams had been mined, but certain zones were not mined, as can be seen in Fig. 2. Underground access was by two vertical shafts that were situated in the center of the circular, unmined area (around the coordinates of latitude 51.025°N and longitude 5.370°E) and at a distance of about 110 m of each other. In Fig. 2, central location of the two vertical shafts is indicated by a dot. In the area that we studied, the mining depth varied between 565 and 888 m. At a certain *X-Y* position with mining underneath, 2–7 different coal seams had been mined. The total height mined over several seams varied between 2.8 and 9.9 m within this area. The mining height for an individual panel varied between 1 and 2 m, of which normally 10–40 cm were layers of waste rock. The slopes of the seams varied between 9° and 24°, with a dip direction between N30°W and N25°E.

In the area that we studied, the mining occurred between 1939 and 1968. However, most of the panels were mined between 1940 and 1960.

The coal seams mined in the Campine Basin in northeast Belgium belong to the Upper Carboniferous strata (Westphalian stage), the time of the formation of many coals fields in the world, especially in Europe [19,20]. The Campine Basin is part of the extensive South Permian Basin of northwestern Europe. The boundary between the Variscan and the Caledonian rocks in the subsurface is expressed by an angular unconformity, pointing to a major tectonic event that occurred at that time, namely in the earliest Devonian time period. The top of the Upper Carboniferous strata, 308 millions of years (shortened as Ma), Westphalian stage, generally occurs at a depth between about 400 and 600 m. Table 1 shows the full stratigraphic column of the overburden, whereby the various aquifers and aquitards also are indicated. The two most important issues are that (1) relatively weak geological material (e.g., sand and clay) are present in the overburden and (2) several aquifers and aquitards are present over the entire section.

The total integrated stratigraphic thickness of the Upper Carboniferous strata has been estimated to be about 3500 m, but only the upper part is being mined. In the coal strata that is being mined, the waste rock is composed mainly of shale, siltstone, sandstone, and thin (unmined) coal layers. Overall, the successive strata are relatively thin (on the order of decimeter to meter in scale). At certain depths, massive quartz sandstone changing into orthoquartzite is recorded, but the overall thickness of this material is small.

The Campine Basin is transected by a predominant set of NNW-SSE striking normal faults, which locally display a shear component. Most of these faults already existed during the Carboniferous period. The most striking ones were reactivated during the Jurassic period. Locally, the NNW-SSE striking faults