Construction of the geological model of the "Knurów" deposit and its application to the exploitation design

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Abstract. The "Knurów" deposit is characterized by intense and rich fold and fault tectonics. The model of the "Knurów" deposit includes 11 seams belonging to the Orzesze, Ruda Śląska and Siodłowe layers. Each of these seams is recognized by boreholes, but also properly documented by mining, which greatly facilitates the modelling of its surface. The article addresses selected issues related to the construction of a three-dimensional model of the deposit. The method of modelling the surface of the terrain and the erosion surface of the Carboniferous is presented, which are used to calculate the location of subcrops of modelled seams and to predict the deformation of the terrain under the influence of mining. The general principles of fault modelling are presented, and so are ways of designing mining surfaces in longwalls passing through a fault. In the analysed deposit there are also seam splits. The article discusses the principles adopted for the development of the deposit model and its visualization, as well as the use of a dedicated algorithm for calculating the location of mining surfaces in such zones.

1 Introduction

Constructing the geological model of a coal deposit is a meticulous process that involves gathering and analysing various data to create a comprehensive representation of the deposit's structure, composition, and characteristics [1]. This model serves as a crucial foundation for designing the most efficient and effective methods for exploiting the coal deposit [2]. The construction of the geological model involves integrating data from geological surveys, drilling exploration, geophysical studies, and other sources to understand the distribution and geometry of coal seams, as well as the surrounding rock layers and geological features [2 – 4].

The geological model is established, it becomes a valuable tool for exploitation design [5]. Such models are used to visualize the spatial layout of the coal seams, identify optimal locations for mining operations, and assess potential challenges or risks associated with extraction [6]. By simulating different mining scenarios and analysing the geological model,

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it is possible decisions about mining methods, equipment selection, mine planning, and resource optimization [7 – 9]. This ultimately leads to more efficient and sustainable coal extraction practices while maximizing the economic viability of the operation [10, 11].

"Knurów" coal deposit, which covers layers of the Namur and Westfal (Upper Carboniferous), is developed from coal seams of the Orzesze layers (seams of group 300, Westfal B), Ruda Śląska layers (seams of group 400, Westfal A), the Siodłowe layers (seams of group 500, Namur B-C) and the Poręba layers (seams of group 600, Namur A). The deposit is layered with packets of sedimentary rocks such as claystone, siltstone, sandstone, and conglomerate. It is characterized by intensive fold and fault tectonics related to the proximity of two large dislocation zones of regional importance. These are the Orłów-Boguszowisze overthrust and the Michałkowice-Rybnik overthrust located in the western part of the mining area. There are four major fault zones and several smaller faults located throughout the deposit area. From north to south, the deposit is traversed by a fold zone called the "Knurów anticline," consisting of two saddles and two benches. The northern part of the deposit (excluded from mining) is dominated by a series of overthrusts, while the part south of the "Knurów anticline" has the character of a monocline declining to the SE at an average angle of 15° [12]. The thickness of the mined seams and those scheduled for further exploitation is between 1.50 m and over 6.0 m. The deposit has been recognized and documented to the level of 1050 m. The dominant types of coal according to PN-82/G-97002 are type 34.2 gas-coking and 35.1 ortho-coking [13]. According to the UNECE classification it can be classified as ortho-bituminous and meta-bituminous. It is a high and medium quality coal suitable for the production of high-quality coke and the rank of coal increases with the depth in the vertical profile [14].

In 2018 – 2020, the "Knurów" deposit was included in the implementation of the Demand and Quality Driven Production Management System. One of the main goals of the implementation was to achieve a stable level of production quality for coking coal customers and coke producers. This goal was to be achieved, among other things, by applying methods of digital geological modelling of the deposit and basing mining production planning on the developed computer model of the coal seams planned for exploitation [15]. During the construction of the model, various aspects of the geological structure of the deposit were analysed, such as: deposit overburden thickness, thickness and quality parameters of coal seams in Orzesze layers (seams of 300 group), Ruda Śląska layers (seams of 400 group) and Siodłowe layers (seams of 500 group), discontinuous dislocation zones and fold zones [16, 17].

The article presented here discusses some aspects of the construction and use of the "Knurów" deposit model. It presents how to build a model of the erosion surface of the Carboniferous, selected elements of faults modelling and their use in the design of mine workings, as well as modelling of splitting zones in seams and the definition of mining surfaces in their surroundings, limiting the designed mining longwalls from below and above.

2 Methods and methodology

The modelling initially covered coal seams included in the strategy until 2030. In subsequent years, the model was expanded to include further seams. In the "Knurów" deposit, eleven of the most promising seams scheduled for exploitation in the foreseen period were selected. These are the seams: 355 (Orzesze layers), 401/1, 401/2, 405/1, 405/3, 408/1, 408/2, 407/1, 407/3 (Ruda Śląska layers), and seams 504 and 507 (Siodłowe layers). The choice of these seams was dictated by market demand for coal with appropriate quality parameters, their accessibility, thickness, and rational management of the deposit. Some seams are significantly depleted, which in the context of making a three-dimensional model of the deposit translates into a very good recognition of the geological situation (layout of disturbances, seams, and surrounding rock layers). This makes it possible to correctly model the surface of less-recognized seams by copying the trends of layer deposition throughout the deposit. For the purposes of the model, a scheme was created to define stratigraphic succession and relations between seams, including the predefined possibility of forming splits (Fig. 1). For correlating models of adjacent deposits (the “Szczygłowice” and “Ornontowice” deposits), a separate codification of seams was created, which is a common nomenclature for all models.

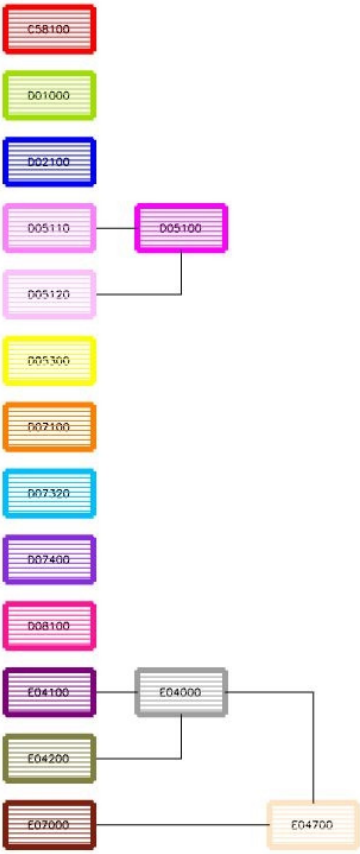

Fig. 1. Schematic representation of seams modelled in the “Knurów” deposit with their nomenclature and stratigraphic succession of the seams in the “Knurów” deposit model.

It should be noted that during modelling, the analysed seams of each group were assigned to geological sequences. Unlike seam structure models created in popular CAD environments [18, 19], in this case, all available structural data was used to build the model: the ascertained ordinates of the roof and floor of seams, their thicknesses and the distances between the seams. This type of approach made it possible to verify in detail the data quality of previous concepts regarding the geological structure of the deposit. The integration of geological, geostatistical, and computational models facilitates the construction of accurate and reliable geological models for coal deposits, which in turn inform and guide the exploitation design process for sustainable and efficient coal extraction [20].

The basis in modelling stratigraphic-type deposits is data from boreholes piercing the resource in question, allowing discernment of the spatial layout of the deposit. An appropriately dense grid of boreholes makes it possible to correlate seams and determine presumed dislocation and fold zones. For the deposit in question, data from surface boreholes (including shaft profiles) and boreholes drilled in underground workings for research purposes were used. The choice of boreholes was dictated by the information they contained about the selected seams. Therefore, for the purposes of the model, boreholes piercing the modelled seams and all surface boreholes were selected. They were also used to model the surface of the Carboniferous roof. At the current stage of creating the 3D model of the deposit, more than 220 boreholes were used.

Due to the scarcity of information in certain areas of the deposit, it was decided to use heading profiles obtained because of geological work carried out by the mine's survey and geological departments. This broadened the information on the geological situation and the layout of the mineral in the deposit. The total number of heading profiles is more than 3.600 for all seams, and a graphical representation of this data after imputing it to the software is shown in (Fig. 2).

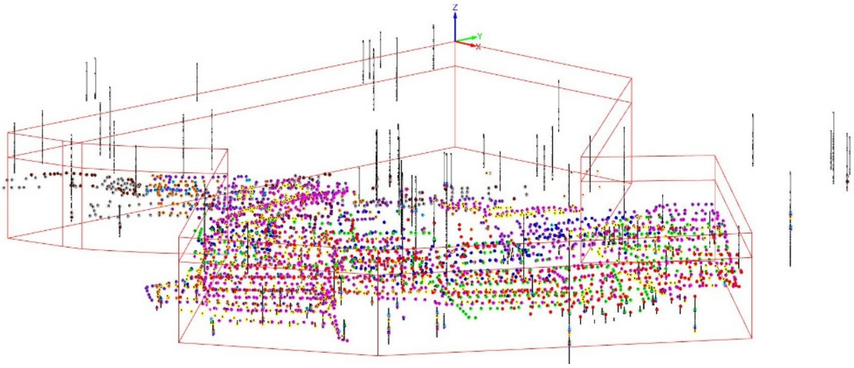

Fig. 2. Location of geological boreholes drilled from surface and mine workings and geological profiles of roadways.

The amount of data is gradually increasing with the ongoing documentation of the deposit, as periodic underground inventory measurements are conducted, and new boreholes are drilled. The data, after being implemented into the software, was used to create a graphic file giving a spatial visualisation of the situation.

3 Results

A thorough study of the geological structure gives an idea of the required result of the modelling process. Viewing the data makes it possible to assess its quality in terms of reproducing the original shape of the deposit. Missing data, on seams or parts of seams where no mining was carried out, or the documentation prepared is sketchy (especially from the pre-war period), should be supplemented with interpreted geological information. Data supplementation in MineScape enables an advanced degree of digitization of surveying and geological documentation in the built-in CAD environment. Of note is the ability to interpolate elevation data when modelling fold zones, for example (Fig. 3). Using 3D contours in the CAD system, one could generate surfaces of interest, e.g. the floor of a seam, and use them to fill in missing data.

Fig. 3. Location of statements of the floor of the seam in the fold region in 405/1 seam (magenta).

Visualization of the database information in MineScape at the next stage of modelling allows for the creation of target cross sections and quality surfaces. An important part of model creation is also the correct design of the regions of the deposit not recognized or recognized to a poor degree.

3.1 Modelling of erosion surface of the Carboniferous and terrain topography

The formation of surfaces limiting the deposit such as tertiary overburden (Fig. 4) or surface topography is one of the necessary elements of the whole process.

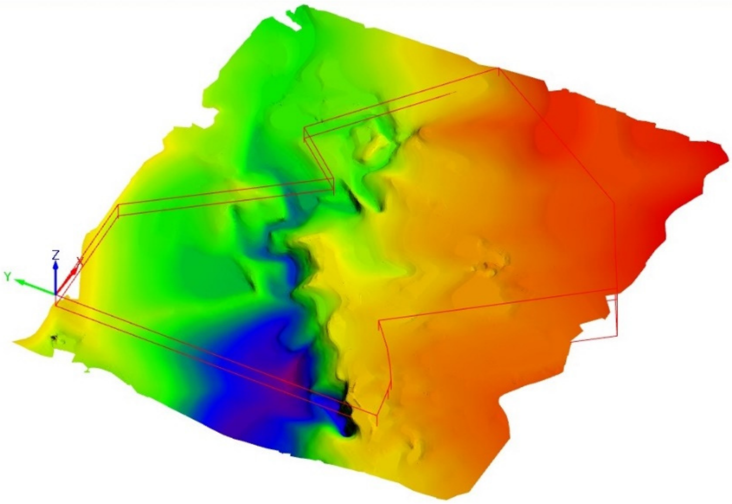

Fig. 4. Presentation of the erosion surface of the Carboniferous floor in the form of a triangular file.

Erosion surface of the Carboniferous as a surface separating two geological sequences can be modelled in two ways. The first is interpolation of the surface from borehole data. The second is to convert 3D contours created by the CAD environment from previous geological interpretation (Fig. 5) and import them into MineScape. The generated surface delimits the deposit by forming the boundaries of the subcrops of the deep seams (Fig. 6). In addition, the surface is used to calculate the deviation of subsidence trough when mining sloping coal seams (Fig. 6). In addition, the surface is used to calculate the displacement of the subsidence basin when mining sloping coal seams [21].

The ground surface was similarly imported from a CAD file. Particularly good results were obtained by using a high-density point cloud acquired by Airborne Laser Scanning. In addition to visualization, this surface can be used to track deformation of ground under the influence of mining. Sufficiently frequent updating of height measurements of the surface in the mining area will enable current, as well as future, observation of land subsidence. In the analysed deposit there were no outcrops of modelled seams on the ground surface.

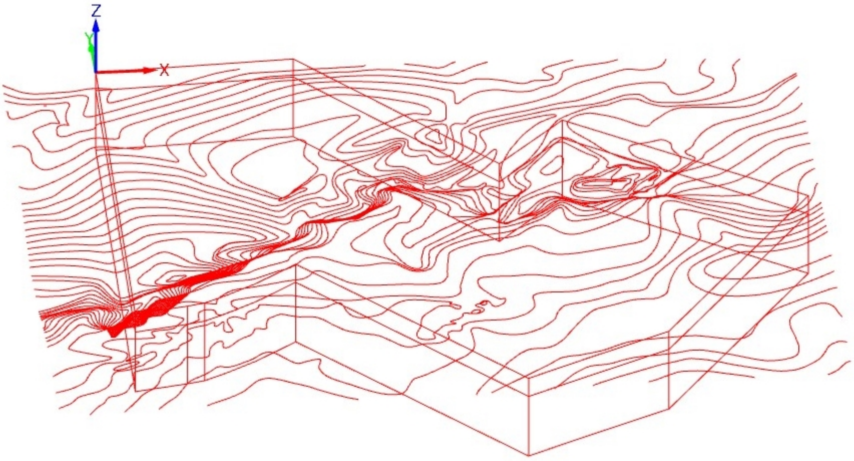

Fig. 5. Erosion surface of Carboniferous, previous interpretation contours imported from CAD into MineScape.

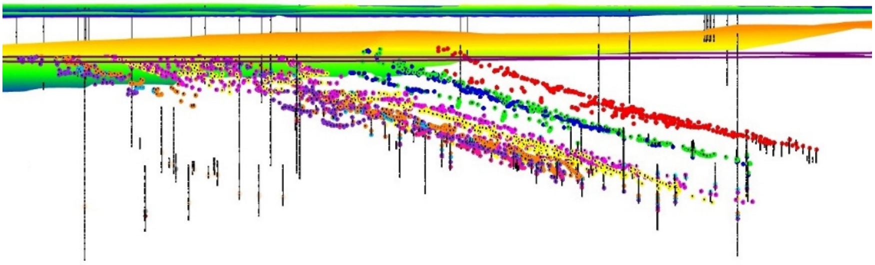

Fig. 6. Vertical projection of ground surface, overburden and borehole data.

3.2 Modelling of discontinuous deformations

The modelling of fault zones in the deposit is a separate stage in the recreating the deposit structure. The need to achieve compatibility of the model with surveying and geological documentation require a compromise between simplification of fault structures and their faithful projection. Each of the four main fault zones is composed of several to a dozen faults, accompanied by smaller accessory faults (Fig. 7). The amplitude of the drop of the latter ranges from 0.5 m to about 2.5 m. In addition, during geological surveys, faults not associated with the main zones and those formed because of mining – the so-called relaxation faults – are also found. Their impact on the shape of the deposit is negligible, as their drop ranges from a few centimetres up to about 1 m.

Due to the inability to create the fault with changing slope of the fault plane in MineScape, it was necessary to adopt an averaged slope. In cases where the change in slope is minor, this solution can be considered valid. In the situation of a significant change in slope, it is necessary to model faults separately for each geological sequence or even seam. At the preliminary stage of modelling, it was decided to represent only the main fault zones based on level maps (450 m, 550 m, 650 m, 850 m, 1050 m) and to set their ranges in a way providing continuity of influence throughout the deposit section.

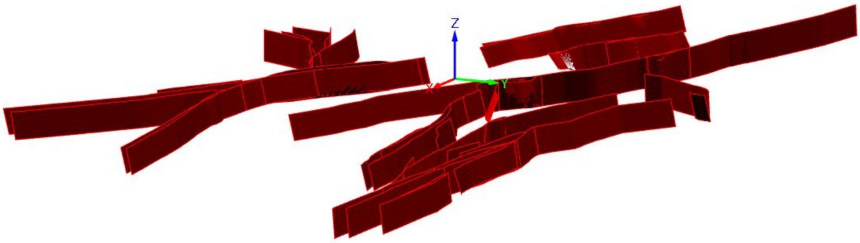

Fig. 7. Modelled fault traces for the 650 m level.

In mining design, longwalls are designed in parcels bounded by, among other things, traces of faults or fault zones with high drops. However, often within the planned longwall, a fault with a smaller drop is found, through which it is possible to advance the exploitation. The effect of the decision to route the longwall this way, however, is the need for a partial protrusion from the seam and mining an increased amount of waste rock. The dedicated algorithm for smoothing top and bottom mining surfaces was developed during the implementation of the system. The algorithm takes into account two main variables defined as the maximum permissible slope of the mining surface in the direction of the advance and in the direction of the face length. For longwalls with a high slope along the length of the face, it is possible to calculate the slope along the length of the face as a relative, related to the average longitudinal slope of the longwall (Fig. 8).

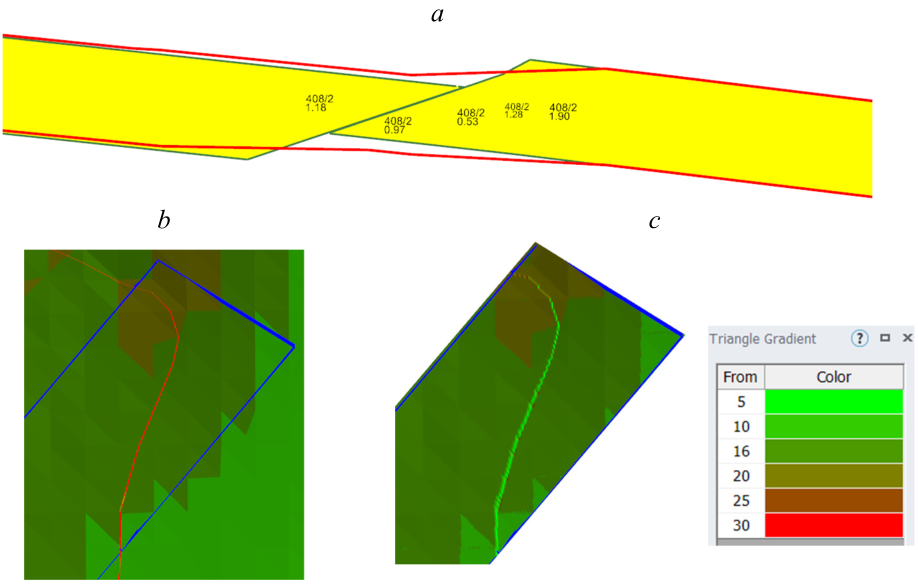

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Fig. 8. Vertical cross-section through the longwall in 408/2 seam in the area of the fault, after smoothing of the mining surfaces (a, in green the layer floors and roofs, in red the mining top and bottom surfaces), and map of the slope of the seam floor (b, edges of the longwall in blue, trace of the fault in the place of the greatest slope) and the smoothed surface of the longwall bottom mining surface (c). Thickness of the seam in meters, slope in degrees.

3.3 Seam splits modelling

The modelled deposit contains several seams with splits, including multiple splits (see Fig. 1). The modelling process always uses elementary units covering the most detailed level of fission. However, it is possible, for the purposes of resource calculation or data exchange with other systems, to define a minimum distance between modelled units, below which elementary seams are presented as one compound seam. In accordance with the requirements of Polish law, this distance is defined in the project as 0.3 m. However, in the process of model construction and verification, the view of elementary units is often used (Fig. 9b).

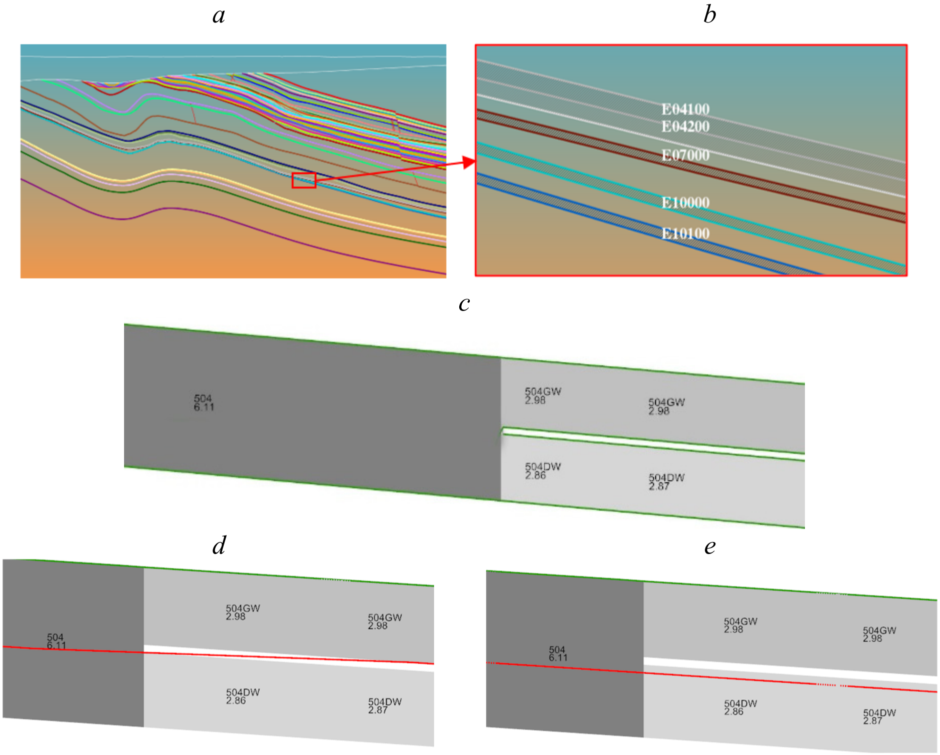

Fig. 9. An example of the 504 seam split into two layers 504GW and 504DW, along with the thicknesses of the layers in meters. Vertical cross-section view through the geological model (a) along with an enlargement of the fragment (b), layers 504GW and 504DW are E04100 and E04200, respectively. Vertical cross-section in the Deswik.CAD planning module (c), geological surfaces of the seam's roof and bottom in green). View of the mining surfaces for the maximum mining height of 3.4 m (d) and 3.6 m (e), bottom mining surface in red.

The deposit model submitted to the mining design and scheduling module (Deswik.CAD) contains seams that, for distances between them of less than 0.3 m, are treated as a compound seam. Such a distance, however, often does not determine the actual position of mining surfaces in the split zone of the seam. An algorithm developed during implementation of the system is used to design the height of longwall in such zones. It considers the location of 4 surfaces:

- the upper surface of the seams – the combined surface of the roof of the compound seam and the roof of the upper split;
- surface of the upper split floor;

- surface of the lower split roof;
- bottom surface of seams – the combined surface of the compound seam floor and the lower split floor.

In addition, the algorithm allows you to control the process of calculating the operating area based on several parameters, defined locally in calculation points distributed in a regular grid over the seam area. The grid size is defined by the user and typically ranges from 5 to 20 meters. Additional control parameters include:

- location of main control surface – mining along the roof or floor of the seam;
- the minimum height of a longwall complex;
- the maximum height of a longwall complex;
- the maximum recommended thickness of the waste rock layer between the split seams.

Analysis of the position of individual surfaces and the values of the control parameters at the calculation points makes it possible to estimate what the possible benefits (the amount of additional coal obtained) and costs (the amount of additional waste obtained) are when trying to mine to maximum equipment height and attempting to mine both splitted seams (see Fig. 9d and Fig. 9e), and chooses the more favourable position of the exploitation surface. The parameter of the maximum recommended thickness of the waste rock layer between the split seams allows to additionally consider the priority of maximizing the amount of coal (for the thickness of waste rock not exceeding the limit value) and minimizing the amount of waste (for the thickness of waste rock higher than the limit value).

4 Discussion

The developed deposit model is used primarily as a tool to optimize mining production by stabilizing the quality parameters of mined coking coal. However, the use of a three-dimensional environment for modelling the deposit made it possible to look more broadly at the geological structure of the deposit and its overburden.

In particular, the enrichment of the model with the erosion surface of the Carboniferous and the terrain surface enables wider use of the model in locating the subcrops of the modelled seams and in predicting subsidence associated with mining. The complex tectonics of the deposit required analysing the course of faults independently in geological sequences or even individually assigning them to seams. A smoothing algorithm was developed to design exploitation passing through minor faults, considering technical constraints and the resulting maximum slopes in the direction of advance as well as the length of the longwall.

The deposit model also includes seam splits. The analysis of this type of situation can be carried out in terms of verifying the correctness of the model, visualizing the data on cross sections or geological maps, or in terms of reporting resources. In each of these situations, a different rule for separating connected seams can be applied. According to the requirements of Polish law, for resource calculation and mining design, 0.3m is accepted as the limiting distance between splitting layers. However, in mining design, it is necessary to consider the possibility of fully utilizing the resources of the deposit on the one hand and limiting the amount of waste rock in the ore on the other. The applied algorithm for calculating mining areas in the seams splitting zones allowed to determine the priority of the amount of coal obtained or minimize amount of waste.

5 Conclusions

This article describes the modelling and operational considerations for mining a deposit containing multiple seams with splits. The deposit contains several seams with splits, and the modelling process involves representing these seams with elementary units. A minimum distance between modelled units is defined, below which elementary seams are presented as one compound seam. In the submitted deposit model, seams less than 0.3 meters apart are treated as compound seams. However, this distance may not accurately determine the mining surfaces' actual position in the split zone of the seam.

An algorithm is developed to design the height of longwall mining in split zones. It considers the position of four surfaces: the upper surface of the seams, the surface of the upper split floor, the surface of the lower split roof, and the bottom surface of seams. This algorithm allows control over the mining process based on various parameters, including the location of the main control surface, the minimum and maximum height of the longwall complex, and the maximum recommended thickness of the waste rock layer between split seams.

Analysis of individual surface positions and control parameters at calculation points helps estimate the benefits (additional coal obtained) and costs (additional waste obtained) of maximizing equipment height and mining both split seams. This analysis aids in choosing the most favourable exploitation surface. The parameter of the maximum recommended thickness of the waste rock layer between split seams prioritizes maximizing coal extraction while minimizing waste production.

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