E3S Web of Conferences **526**, 01018 (2024) https://doi.org/10.1051/e3sconf/202452601018
SEP 2024

Predicting surface mining influences in an integrated mining design and planning system

Dominik Galica[1*], *Leszek* Malinowski[1], *Joanna* Kuchenbecker-Gacka[2], and *Tomasz* Frycz[2]

[1]Mineral and Energy Economy Research Institute, Polish Academy of Sciences, 7A Wybickiego St., 31-261 Cracow, Poland
[2]KWK Knurów-Szczygłowice, 1 Dworcowa St., 44-190 Knurów, Poland

Abstract. While planning the exploitation of a deposit, the volume and quality of coal in the longwall parcels are taken into consideration, however, designers must consider many other aspects and among them, the influence of the planned mining on the ground surface. This article presents the possibility of using the Subsidence module, integrated with mining planning tools, to perform approximate analyses of the mining influence on the surface. The assumptions of the calculation model used in the module are presented, including the general characteristics of the influence function used for forecasting. The results of the prognosis for two longwalls were compared to a reference solution routinely used to perform this type of prognosis. The differences resulting from the use of a simpler calculation model and a different method of calculating horizontal displacements were characterized. The advantages of integrating spatial data about the deposit, the projected exploitation, and its effects, which allowed a much faster assessment of the scale of projected deformations and basing the calculations on detailed geological and mining data, were also presented.

1 Introduction

Predicting surface mining influences within an integrated mining design and planning system entails using advanced analytical methods and modelling techniques to anticipate and evaluate the various impacts, both positive and negative, that surface mining activities may have on the environment, local communities, infrastructure, and overall project sustainability [1 – 3]. Effective management strategies are then implemented to safeguard groundwater resources, prevent contamination from mining activities, and ensure an adequate supply for both human consumption and ecological needs [4 – 6]. This involves conducting comprehensive hydrogeological assessments, establishing appropriate monitoring systems, and adopting innovative technologies for water treatment and recycling [7, 8].

JSW S.A.'s ongoing efforts to better plan the production and quality of coking coal led to the construction of an IT system, which supported deposit and mining production management. This system uses tools for three-dimensional deposit modelling and model-based software for designing and planning mining operations [9, 10]. The implemented tools served primarily as a basis for economically efficient deposit management making use of the knowledge aggregated

[*] Corresponding author: dgalica@meeri.pl

in the deposit model. In the case of the Knurów mining operation, the model covered 20 coal seams [11, 12], and the strategic exploitation schedules conducted in 10- and 30-year horizons consisted of a total of about 50 longwalls (Fig. 1). Minescape software is used to model the deposit while the planning part is performed in Deswik software [9, 13].

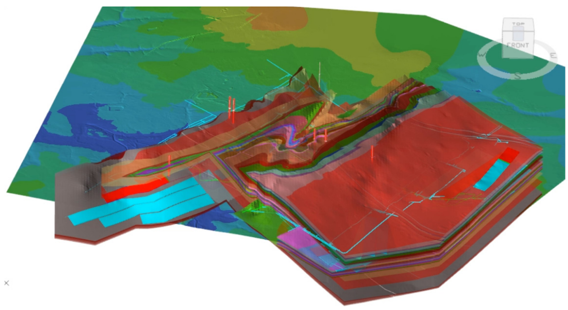

Fig. 1. A view of the coal seams from the deposit model, the ground surface and selected mine excavations.

The Knurów movement has a mining history of more than 100 years. An important issue in mining planning is surface subsidence which results from exploitation carried out in a rock mass disturbed by previous activities. Prediction of surface deformation has so far been carried out with the use of computational programs using the Budryk-Knothe theory [14] widely used in Polish coal mining [15]. In particular, in the Knurów movement, EDN software [13, 16] was used for this purpose. However, this software is not an integrated system based on a three-dimensional model of the deposit, and any analysis of a mining project requires performing iterative actions of exporting data on geometric features, scheduling of mined plots, and importing results of subsidence modelling. Data derived from the deposit model can be simplified which may have some impact on calculation results.

The Subsidence module is as well implemented in Deswik software for calculating subsidence directly based on predefined influence functions and on the basis of designed and scheduled mine workings. Among the available influence functions, the function described by Knothe [14, 15] is also available. The use of this tool in current planning work would make it possible to use full information about the geometry of the deposit and mine workings in the prediction of ground deformation, as well as to receive modelling results directly after the execution of the workings schedule. It would also fit in with the efforts postulated in the field of mining geomatics to integrate spatial data about the deposit, the planned exploitation and its impact [17].

The article describes the integrated design, scheduling tool Deswik together with the module forecasting mining impact on surface. An analysis of the use of this tool on 2 selected longwalls was carried out and the results were compared with those of a reference EDN solution [9, 18]. The conclusions present the possibilities of using the Deswik Subsidence module as a tool to quickly analyse a project in terms of its influence on the surface [19].

2 Methods

2.1 Budryk – Knothe influence function

The Subsidence module of Deswik software allows to use the function defined by Knothe to calculate the predicted influence of mining on the surface. According to the assumptions of the Budryk-Knothe theory, the vertical displacement of the subsidence trough within the limits of an infinite half-plane is determined by the formula [14]:

 https://doi.org/10.1051/e3sconf/202452601018

$$\Delta Z = \iint a_0 \frac{1}{R} \cdot e^{-\frac{\pi r^2}{R^2}},$$

where R is the radius of the extent of the main influence; r is the distance from the elementary unit; and a_0 is the subsidence factor (dimensionless parameter), representing the ratio of the maximum theoretical settlement to the maximum physical value.

Other deformation indices important for determining the category of a mining area can can be calculated using the following correlations [20]:

- The slope of the terrain of the subsidence trough profile defined as:

$$T = \frac{\Delta Z}{R} \cdot e^{-\frac{\pi r^2}{R^2}}.$$

- Curvature of the subsidence trough profile:

$$K = -2\pi \frac{\Delta Z r}{R^3} \cdot e^{-\frac{\pi r^2}{R^2}}.$$

- Horizontal displacements are defined assuming their proportionality to the slope:

$$U = -B \cdot T,$$

where B is the proportionality factor represented by the formula:

$$B = -B_0 \cdot R.$$

- Horizontal strain is defined as the first derivative of the horizontal displacement:

$$\varepsilon = -B \cdot K.$$

2.2 Use of number model of calculation

The numeric method used in the Subsidence module is analogous to that described in the work of Ren, Reddish and Whittaker [21]. The impact of the elementary extracted volume on the subsidence of the surface area is examined. Beyond the Angle of draw, the influence is assumed negligible (Fig. 2).

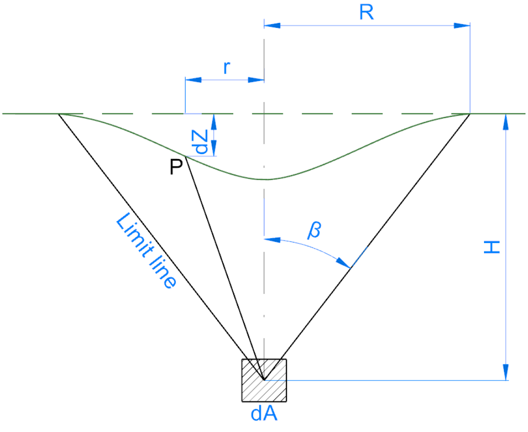

Fig. 2. A schematic diagram illustrating the influence function based on the extracted deposit element, where dA - elementary deposit fragment, β – angle of draw, H – depth, R – influence range radius, r – the distance of point P from the elementary unit, dZ – the subsidence at point P (based on the [21]).

The calculations performed by the tested module involve generating a grid of points from the input topographic surface. Calculations of deformation indices are then performed for these points, and the points are moved in space to form the final surface, after subsidence.

The value of angle of draw was defined in the module by a different convention and was entered as the complement of the angle shown in the figure (Fig. 2) to 90 degrees. In addition to the choice of influence function, subsidence factor and angle of draw, the parameters used in the calculations also include information used in calculations for tilted seams:

- seam dip angle;
- dip azimuth;
- dip angle deviation factor;
- carboniferous surface layer – surface within the overburden that represents the boundary between soft and hard rock.

Theories describing horizontal displacement assume the displacement of surface points in the direction of the centre of gravity of the selected seam element, or are based on the relationship between the vertical and horizontal displacement values of a point [22]. The tested Subsidence module uses the first of these assumptions in contrast to the reference EDN solution. Therefore, in the tested module, it was not possible to introduce the B-value factor required to calculate horizontal displacements in a manner comparable to EDN. The calculation of horizontal displacements was performed in post-processing by analysing the vertical displacements of the end points of the subsidence surface.

It is also important to note that, unlike the EDN solution, the Subsidence module does not have parameters describing the exploitation boundary and the effect of rock mass relaxation, which can significantly affect the predicted course of ground deformation. Exploitation edge is not a parameter of the Budryk-Knothe theory, however, in order to achieve consistency of prognosis with observations, it is used in numerical solutions by modifying the position of the exploitation boundary [23].

The Subsidence module also allows the application of a time factor to include a delay in occurrence of subsidence on the surface. As part of the tests, this functionality was activated but its results were not analysed in detail.

2.3 Data for calculations and key settings

To use the module there have been prepared:

- a digital terrain model of the land surface obtained from aerial laser scanning points and developed as a grid surface,
- digital model of the deposit as solids of the seams planned for mining,
- digital model of the carboniferous roof as a grid surface,
- designed walls in the form of task solids in the Deswik Suite software, divided into segments with a length of 25 m, along with attributes of their exploitation periods.

Each of the segments of the analysed longwalls is treated separately and has individually estimated values for the slope of the seam, which can be important in calculating the location of the final subsidence trough [24].

In addition, the parameters adopted for the calculations:

- $tg\beta = 2.0$;
- $a_0 = 0.9$;
- Deviation factor = 0.7;
- $B_0 = 0.32$;
- Time factor = 2.0;
- Mesh of the calculation grid = 10 m.

Fig. 3 presents an example window of Subsidence module settings. The land surface model, seam model, carboniferous roof model, influence function, angle of draw, subsidence factor, deviation factor, result surface and its resolution are adopted.

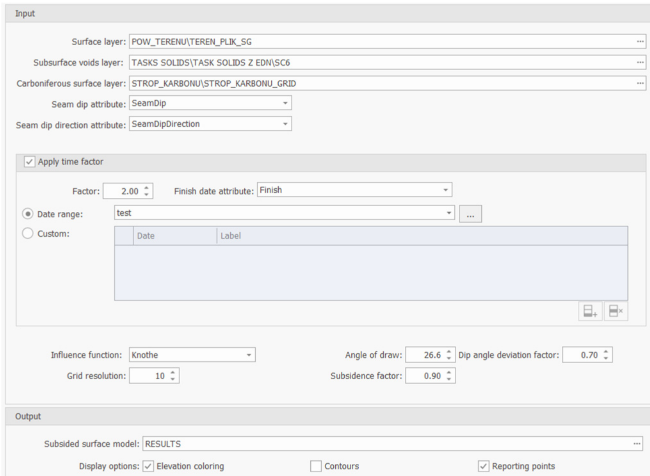

Fig. 3. Settings of the integrated module for calculating projected mining influences.

3 Results

The functionality of the module was tested on real examples from the Knurów-Szczygłowice coal mine. The first simplified test was carried out on the example of a single wall at a depth of about 600 m. Only calculations in terms of calculated maximum final subsidence were tested. Deliberately, no data on the tilt of the exploited seam were entered.

Fig. 4 presents the ground surface, and the floor of an example seam with a projected wall, as well as the area of projected influences and the creation of a subsidence trough. For proper analysis of the data, as reference results, data were obtained with calculations of projected mining influences from the surveying and geological department in the EDN software. A comparison in terms of the projected maximum subsidence showed that the difference is negligible, on about 2% of the reference value.

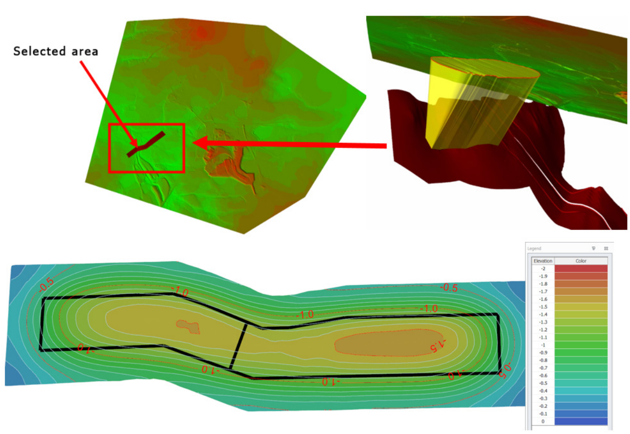

Fig. 4. First selected wall for preliminary analysis against the terrain model with approximate extent of mining influence on the surface and resulting contours of final subsidence, values in meters.

For in-depth testing, researchers chose a wall characterized by high variability seam slope, located at a depth of more than 700 meters, with a thickness of more than 2 meters and a length of almost 2 kilometres (Fig. 5).

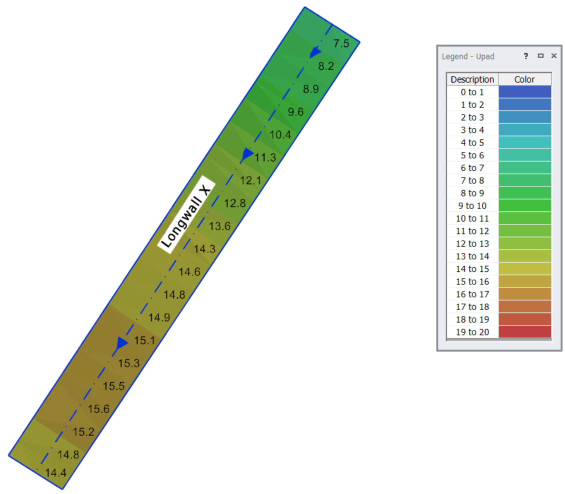

Fig. 5. The second wall selected, the legend shows seam dip angle, values in degrees.

As a result, the surface was obtained in the form of a regular grid of topographic surface points dislocated from their initial position by the values resulting from the predicted deformations. Surface deformation parameters were calculated for these points: curvature, strain, displacement, slope and subsidence. These parameters were entered as attributes for each point separately (Fig. 6). Based on these attributes, value surfaces and contour maps of the parameters in question were created.

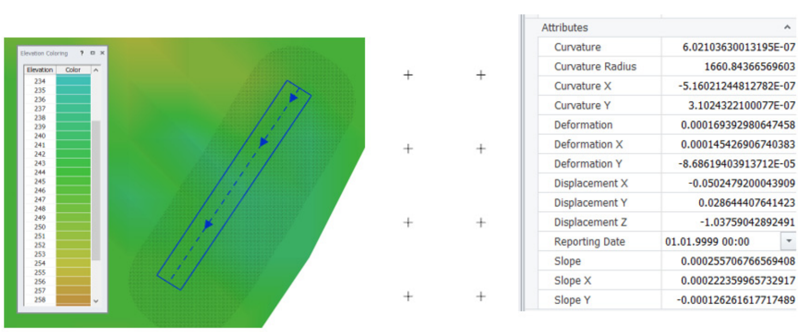

Fig. 6. Resulting ground elevation surface [m] and calculated values for an example point on the surface.

Once again, as reference data, results of EDN program calculations prepared by the surveying and geological department were used. The obtained shape of the subsidence trough is compared in Fig. 7.

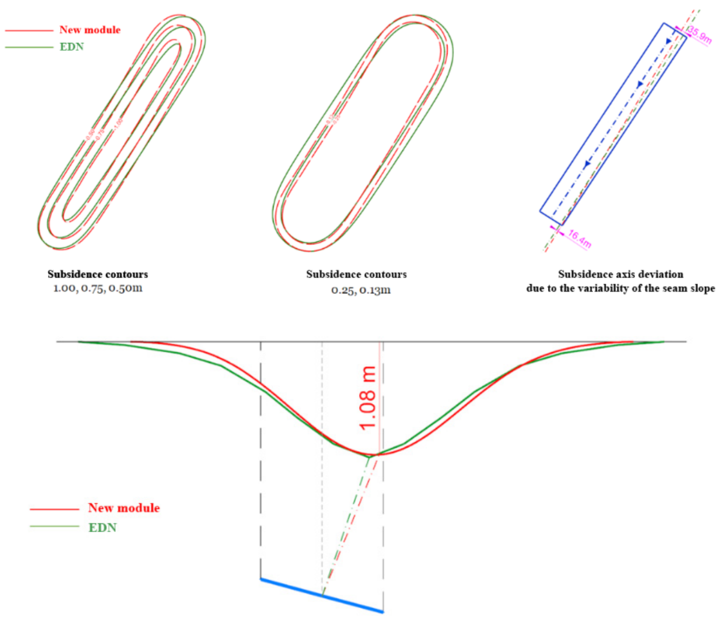

Fig. 7. Comparison of the shape of the subsidence contours in plan and on the cross-section through the wall axis.

Descents of 1 to 0.5 meters in the Deswik module cover 2% more area than the reference, while smaller subsidence of 13-25 centimetres has a 12% larger range in the EDN than in the new Subsidence module. In addition, in the Subsidence module data there is a deviation of the axis of the trough by about 1.5 degrees relative to the EDN, which is probably related to the variable slope of the longwall. A cross-section through the wall's axis shows a displacement of the trough axis of about 1m and a difference in maximum subsidence of less than 0.1m.

Due to the lack of data on slopes and horizontal strain in the reference data, these values are presented below without commentary in terms of their correspondence with the values from the EDN. However, a comparison of the final result is made in terms of the projected mining area categories, which take into consideration the maximum values of slopes, curvatures and horizontal strain.

The course of the maximum slope values over the edges of the parcel varies from +4.2 to -4.1 mm/m (Fig. 8). The radius of curvature in the section made in the middle of the wall length is -42 km and 22 km, respectively (Fig. 9). The calculated strain (Fig. 10) is in the range of +3.1 to -5.7 mm/m.

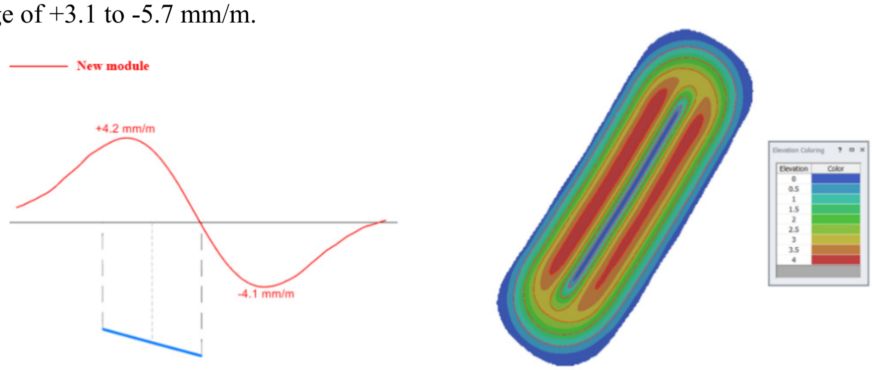

Fig. 8. Cross-section and contour map of absolute values of maximum gradients, values in mm/m.

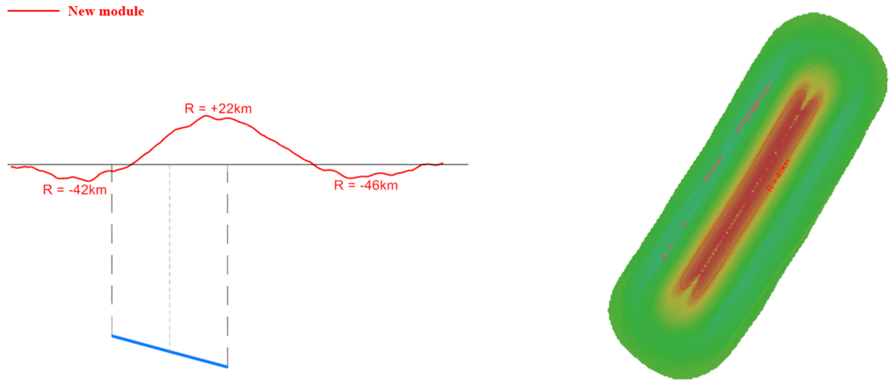

Fig. 9. Cross section and contour map of the radius of curvature, values in km.

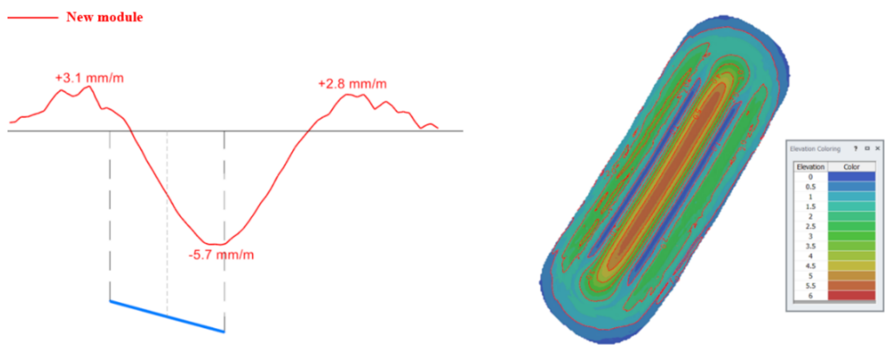

Fig. 10. Cross section and contour map of maximum horizontal strain.

For both tools used, a maximum of category III mining area is predicted. Both category III and category II had their range predicted in the new Subsidence module, giving values that were bigger than in EDN by 59 and 41%, respectively (Fig. 11). At this stage of the work, however, it was not possible to compare categories I and 0 of the mining area, due to excessive clipping of the calculation results around the analysed area by the new Subsidence module.

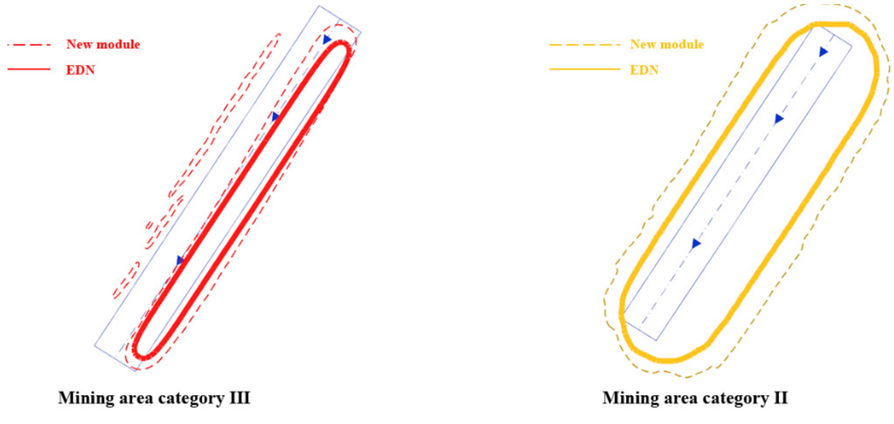

Fig. 11. Comparison of the extent of category III and II of mining area.

4 Discussion

The use of the new integrated Subsidence module made it possible to estimate the influence of the planned mining on the deformation of the ground surface much more quickly. It was also possible to assess the category of the mining area and the associated intensity of influence on objects on the surface already at the stage of designing the exploitation. The high degree of integration of spatial data expected from this type of tool was achieved. A similar research result was also obtained in references [18, 25, 26].

It was assessed that the conformity of the prognosis in terms of maximum subsidence and deviation of influences over the exploitation in the inclined seam compared to the reference solution is very high. In addition, the adoption of the inclination of the seam at the longwall axis according to the three-dimensional model of the deposit and combined with the model of the carboniferous roof surface resulted in a variable deviation of the trough axis from the axis of the designed longwall.

Due to the inability to determine the coefficient of proportionality of horizontal displacement to slope, the Subsidence module did not allow to calculate strain in a comparable way to the reference solution. These values were calculated in an additional step on the resulting grid of calculation points. The limited range of reference data in terms of slopes, curvatures and horizontal deformations meant that a detailed comparison of these values was not possible. However, the results of the comparison of the range of mining area categories indicate that the same mining area categories were determined, however, their projected ranges in the new Subsidence module are clearly larger than in the reference solution. This is probably due to the additional calculation parameters adopted in the reference solution to describe the effect of mining edge and relaxation [17] which are not present in the Budryk-Knothe theory [23] and were also not used in the Subsidence module described.

5 Conclusions

Authors of the article presents the testing and evaluation of a newly integrated Subsidence module designed to assess the impact of mining activities on ground surface deformation. Initial tests conducted on real examples from a coal mine demonstrated close agreement, with only a negligible difference of approximately 2% observed in calculated maximum subsidence compared to reference values. Subsequent in-depth testing on a longwall face characterized by significant variability in slope revealed differences between the new module and the reference software (EDN), particularly in the shape and extent of subsidence forms, as well as deviations in trough axis and maximum subsidence.

Surface deformation analysis was conducted using the module, which generated a regular grid of topographic surface points displaced by predicted deformations. Parameters such as curvature, strain, displacement, slope, and subsidence were calculated and mapped to provide insights into the ground surface changes resulting from mining activities. The comparison of results highlighted discrepancies between the Subsidence module and the EDN software, especially concerning smaller subsidence values and the projection of mining area categories, with the new module generally predicting larger ranges for certain categories.

It was noted that the tool allowed for quicker estimation of mining impacts and assessment of mining area categories. Despite high conformity between the module's predictions and the reference solution for maximum subsidence and deviation of influences over the inclined seam, limitations were identified in calculating curvatures and deformations compared to the reference solution. These differences in projected mining area categories were attributed to the absence of certain calculation parameters in the Subsidence module, suggesting the need for further refinement to align more closely with reference solutions and address limitations in deformation parameter calculations.

References

1. Büsching, R.H. (2020). Continuous surface miners – A mining system for hard materials and selective mining. *Continuous Surface Mining*, 211-220. https://doi.org/10.1201/9781003079422-26
2. Mendygaliyev, A., Mendygaliyev, Y., & Yazikov, E. (2022). Orthogonal-contour geometrization of hydrogenetic ore mineralizations. *Engineering Journal of Satbayev University*, *144*(3), 30-33. https://doi.org/10.51301/ejsu.2022.i3.05
3. Polyanska, A., Savchuk, S., Dudek, M., Sala, D., Pazynich, Y., & Cicho, D. (2022). Impact of digital maturity on sustainable development effects in energy sector in the condition of Industry 4.0. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 97-103. https://doi.org/10.33271/nvngu/2022-6/097
4. Polyanska, A., Pazynich, Y., Mykhailyshyn, K., & Buketov, V. (2023). Energy transition: the future of energy on the base of smart specialization. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (4), 89-95. https://doi.org/10.33271/nvngu/2023-4/089
5. Tymoshchuk, V., Rudakov, L., Pikarenia, D., Orlinska, D., & Hapich, H. (2023). Analyzing stability of protective structures as the elements of geotechnical tailing pond safety. *Mining of Mineral Deposits*, *17*(4), 116-122. https://doi.org/10.33271/mining17.04.116
6. Bazaluk, O., Sadovenko, I., Zahrytsenko, A., Saik, P., Lozynskyi, V., & Dychkovskyi, R. (2021). Forecasting Underground Water Dynamics within the Technogenic Environment of a Mine Field: Case Study. *Sustainability*, *13*(13), 7161. https://doi.org/10.3390/su13137161
7. Rudakov, D., Inkin, O., Dereviahina, N., & Sotskov, V. (2020). Effectiveness evalu-ation for geothermal heat recovery in closed mines of Donbas. *E3SWebofConferences*, (201), 01008. https://doi.org/10.1051/e3sconf/202020101008
8. Timoshuk, V., Tishkov, V., Inkin, O., & Sherstiuk, E. (2012). Influence of coal layers gasification on bearing rocks. *Geomechanical Processes During Underground Mining – Proceedings of the School of Underground Mining*, 109-113.
9. Dyczko, A., & Jarosz, J. (2010). Exploitation of thin hard coal beds in Poland – stra-tegic decisions at the threshold of the 21st century. *Mine Safety and Efficient Exploitation Facing Challenges of the 21st Century*, 371-378. https://doi.org/10.1201/b11761-51
10. Dychkovskiy, R., & Bondarenko, V. (2006). Methods of Extraction of Thin and Rather Thin Coal Seams in the Works of the Scientists of the Underground Mining Faculty (National Mining University). *International Mining Forum 2006, New Technological Solutions in Underground Mining*, 21-25. https://doi.org/10.1201/noe0415401173.ch3
11. Dyczko, A. (2023). The geological modelling of deposits, production designing and scheduling in the JSW SA Mining Group. (2023). *Gospodarka Surowcami Mineralnymi – Mineral Resources Management*, *39*(1), 35-62. https://doi.org/10.24425/gsm.2023.144628
12. Sosnowski, P. (2020). A New Look at the Geological Structure of the Knurów Hard Coal Deposit in Light of Model Tests. *New Trends in Production Engineering*, *3*(1), 186-196. https://doi.org/10.2478/ntpe-2020-0015
13. Dyczko, A. (2023). Construction of a heuristic architecture of a production line management system in the JSW SA Mining Group in the context of output stabiliza-tion, quality improvement and the maximization of economic effects. *Gospodarka Surowcami Mineralnymi – Mineral Resources Management*, *37*(4), 219-238. https://doi.org/10.24425/gsm.2021.139746
14. Knothe, S. (1984). *Forecasting the impacts of mining exploitation*. Katowice: Wydawnictwo "Śląsk", 223 p.
15. Sroka, A. (2018). Knothe's theory – its importance for mining science and the mining industry. *Prace Instytutu Mechaniki Górotworu PAN*, *20*(1), 34-51.
16. Białek, J. (2003). *Algorithms and computer programs for the prediction of mining gound deformation*. Wydawnictwo Politechniki Śląskiej, 132 p.

17. Krawczyk, A. (2023). Mining Geomatics. *ISPRS International Journal of Geo-Information*, *12*(7), 278. https://doi.org/10.3390/ijgi12070278
18. Dychkovskyi, R., Falshtynskyi, V., Ruskykh, V., Cabana, E., & Kosobokov, O. (2018). A modern vision of simulation modelling in mining and near mining activity. *E3S Web of Conferences*, (60), 00014. https://doi.org/10.1051/e3sconf/20186000014
19. Kamiński, P., Dyczko, A., & Prostański, D. (2021). Virtual Simulations of a New Construction of the Artificial Shaft Bottom (Shaft Safety Platform) for Use in Mine Shafts. *Energies*, *14*(8), 2110. https://doi.org/10.3390/en14082110
20. Strzałkowski, P. (2010). *Outline of protection of mining areas*. Wydawnictwo Politechniki Śląskiej, 114 p.
21. Ren, G., Reddish, D.J., & Whittaker, B.N. (1987). Mining subsidence and displace-ment prediction using influence function methods. *Mining Science and Technology*, *5*(1), 89-104. https://doi.org/10.1016/s0167-9031(87)90966-2
22. Tajduś, K., Misa, R. & Sroka, A. (2012). Horizontal displacements in mining areas. *Prace Instytutu Mechaniki Górotworu PAN*, *1*(14), 1-4.
23. Kowalski, A., Jędrzejec, E. & Polanin, P. (2016). Operational edge, its origin and inclusion in surface deformation forecasts in the "Damage" program. *Przegląd Górniczy*, *72*(3), 152-162.
24. Ścigała, R. & Żyła, B. (2016). The influence of the inclination of the exploited seam on the predicted distribution of depressions on the surface, Wiad. *Górnicze*, (67), 7-18.
25. Vu, T.T., & Do, S.A. (2023). Determination of the rock mass displacement zone by numerical modeling method when exploiting the longwall at the Nui Beo Coal Mine, Vietnam. *Mining of Mineral Deposits*, *17*(1), 59-66. https://doi.org/10.33271/mining17.01.059
26. Bazaluk, O., Kuchyn, O., Saik, P., Soltabayeva, S., Brui, H., Lozynskyi, V., & Cherniaiev, O. (2023). Impact of ground surface subsidence caused by underground coal mining on natural gas pipeline. *Scientific Reports*, (13), 19327. https://doi.org/10.1038/s41598-023-46814-5