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Tremors and rock bursts hazards characteristics using the digital model of the deposit in KWK ROW Site Marcel

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Abstract. The article presents data arranged for the purpose of scientific and research development prepared for protective pillar stability assessment including located in it main haulage transportation, and ventilation workings in the part "C" of KWK ROW Site Marcel and the "Z" KWK ROW site Jankowice in relation to the planned and completed exploitation in this area. The article contains: characteristics of geological and mining conditions for the analyzed area, description of digital model creation of the deposit and development. The digital model of the deposit was created based on the materials obtained from KWK ROW: geological borehole profiles, digital files with plots saved in the EDN-OPN format, development and levels mining maps, and tremor record files for analyzed area in years 2015-2018. The Geolisp software operates in a CAD graphic environment and allows for automation of the most frequently performed works in the field of mining map preparation.

1. Introduction

Exploitation of underground hard coal deposits should ensure the greatest possible safety, for both underground and surface facilities. Therefore, part of the deposit is deliberately left in the form of a pillar – unmined coal blocks with various widths. The dimension of the pillar should be selected so that its stability as well as stability of the workings located in it is maintained. The coal pillars have retaining, protection and safety functions [1,2,3].

The goal of the elaboration carries out at the Silesian University of Technology [4], is to assess the stability of the pillar and the main haulage, transportation and ventilation workings located in the part "C" of KWK ROW Site Marcel and the part "Z" of KWK ROW Site Jankowice in connection with the exploitation carried out and planned in its area. The analysis was made on the basis of the following documents and files received from KWK ROW:

- Borehole profiles.
- Digital files in the Prof. Białek format for Site Marcel and Site Jankowice. (The EDN-OPN is the most popular software for prediction of mining ground deformations).
- Mining development maps for seams: 502, 503+504, 505, 507.
- Level maps for Levels 400 and 600.
- Tremor record files for analyzed area in years 2015-2018.

These documents and files were used to create a digital model of the deposit and the model of the development. These models allowed to show the spatial location of the deposit and workings and formed the basis for further calculations.

The article presents the characteristics of geological and mining conditions for the analyzed area, a description of the creation of the digital deposit and development model.

The numerical model of the deposit was used for geomechanical analysis of the rock mass in selected regions of the KWK ROW. The state of stress generated in a numerical model, in which the developed deposit geometry was taken into account, allowed to analyze the stress concentration and to determine potential zones threatened by the occurrence of tremors that may have an unfavorable impact on stability of the near workings.

The developed model also took into account the existing corridor workings located in the protective pillars, while numerical simulations and the rock mass stress conditions made it possible to verify the size of the pillars and determine the safe operation distances guaranteeing stability of the heading workings.

2. General description of the deposit

ROW Mine Site Marcel is a single site and multi-level mine with a rock and coal skeleton. The mine is accessed by seven shafts and a network of workings located on four active operating levels, with production, ventilation and transportation functions

The "Marcel 1" deposit lies in the south-western part of the Upper Silesian Coal Basin within the Jejkowice Basin (the main part) and the Chwałowice Basin (Marklowice part) and is documented within the "Radlin II" mining area [5] (figure 1). The border between these basins is determined by the Michałkowice overlap with an amplitude from 750 m in the southern part to 1500 m in the northern part. The layers dips axial towards bottom of the basin at an angle of approximately 30 ° - 40 ° on the wings and approx. 0 ° - 15 ° in the bottom of the basin. The extent of the layers is variable and adapted to the shape of the basins. The structural-tectonic model of the deposit is shaped by rich fold-fault tectonics, associated with regional dislocations, such as the Michałkowice overlap and the Orłowskie overlap, which are limiting the Chwałowice basin from the east. The faults generally are arranged in two directions: meridional and latitudinal. Large dislocations are usually accompanied by zones of cracks and local disturbances.

ROW Mine Site Marcel is currently mining coal seams exclusively with a longitudinal longwall system with a caving (roof collapse). Due to the specific construction of the "Marcel 1" deposit in the home field located in the Jejkowice Basin (west of Michałkowice), the jaklowieckie layers are being exploited - currently the 712/1-2 and 712/1 2-713/1 seams, which have a thickness up to approx. 3.9 m. In the part of Marklowice located in the Chwałowice basin (east of the Michałkowice basin), the mine conducts coal mining of saddle layers, where the seams reach a thickness of approx. 1.5 m to approx. 8.8 m. the fifth and fifth layers of the 505 and 507 seams are characterized by a large thickness, up to approx. 8.8 m (deck 505).

3. Stratigraphy and lithology

In the profile building the "Marcel 1" hard coal deposit, there are Upper Carboniferous formations – Namur [5]. The oldest part of the Upper Carboniferous in this area is the lower part of the carbonaceous paralical series in the form of the Gruszowskie layers. Carboniferous formations (in the Marklowice basin - the main part on the settlements of the Gruszowskie, Jejkowice and Poręba layers, and in the Chwałowice basin on the sediments of the saddle and Ruda stratas), are covered inconsistently by the Neogene (Miocene) and Quaternary sediments.

4. Morphology of carbon roof and tectonics

The Carbon roof within the "Marcel 1" deposit has a very diverse morphology of erosive character and is covered entirely with loam from Miocene formations [5]. Only in the southern part of the Marklowice area, outside the outcrop of the 503 seam, water affected quicksands have been found directly on the roof. Generally, Carbon roof decreases towards the south, where the Miocene formations reach the largest thickness. The structural model of the deposit was formed during Asturian folds and its essential element is the Michałkowice overlap.

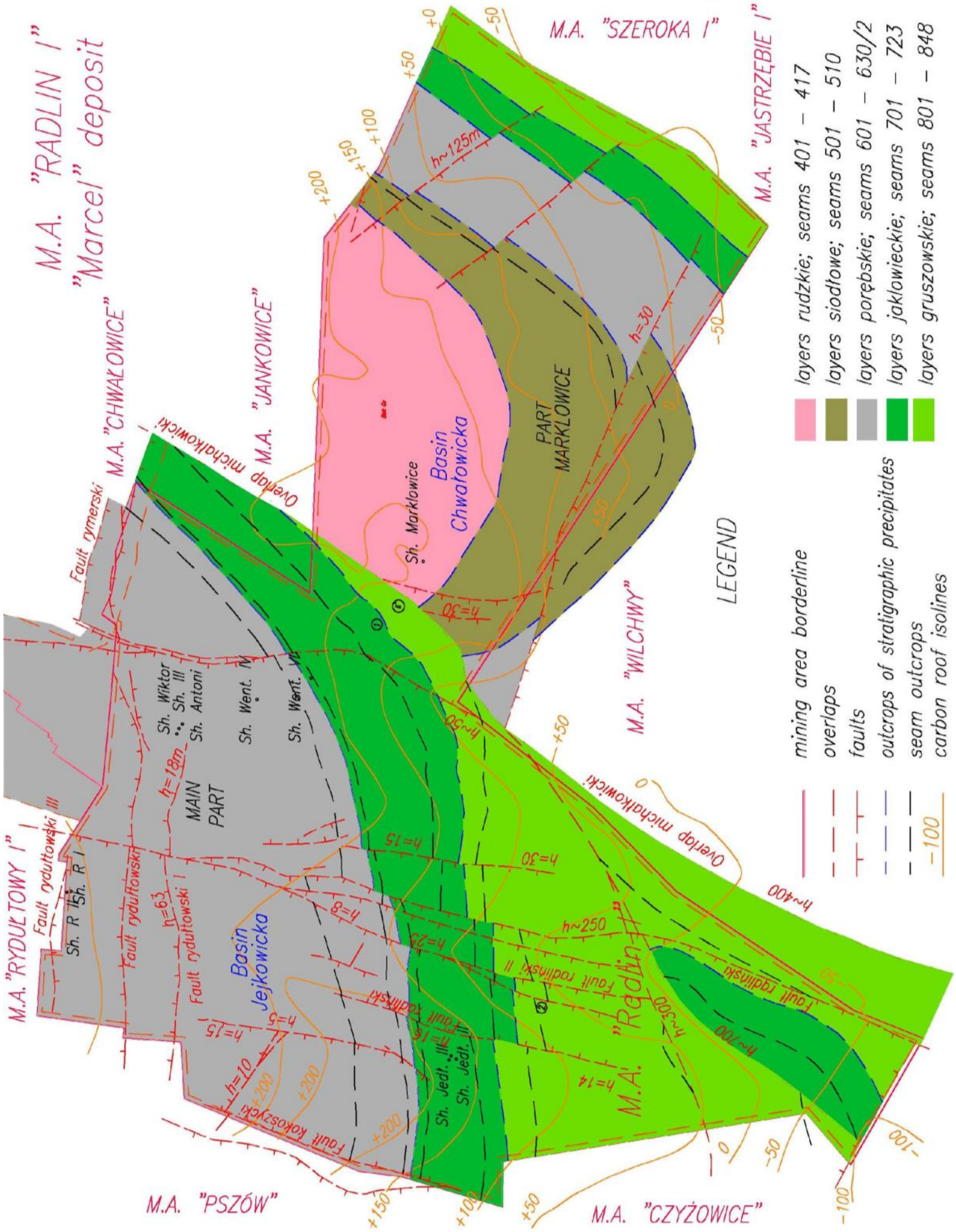

Figure 1. Structural map of "Marcel 1" deposit. Source: P. Kucia. SITG Rybnik.

IOP Conf. Series: Earth and Environmental Science **261** (2019) 012020 doi:10.1088/1755-1315/261/1/012020

In the main part of the deposit, the layers are dipping generally north-west. The slope of the layers on the basin's wings reaches up to 30°, and in the bottom of the basin it ranges from 2° to 5°. The Carboniferous formations were dislocated with numerous faults. There are two basic dislocation directions: the meridian of NNE - SSW and latitudinal (NWW - SEE). The slope of the latitudinal surfaces is 60° - 80°.

In the Marklowice part, the deposit structure is conditioned by its location in the brachysynklinal structure of the Chwałowice basin. The structure has been cut off from the west by the Michałkowice overlap, at which the layers are dipping at an angle of up to 90°. The layers in this part are dipping towards the axis of the basin. The slope of layers vary from 8° - 15° in the central part of the basin to 30° - 40° on the wings of the basin. The Carboniferous formations in the Marklowice part were cut by discontinuous faults of three main directions: meridional (N - S), latitudinal (W - E) and NW - SE with NNW-SSE deviations.

Seams characteristics in the areas of mining operations are shown in table 1.

Table 1. Basic parameters of the seams.

Seam	Part	Thickness [m]	Coal Rc [MPa]	Roof-rock	
				lithologic type	Rc [MPa]
502/2	Cz Cw	1.6 – 1.8	23.2	Clay shale Sandy shale Sandstone	25 – 36 30 – 57 45 – 93
503 – 503 503 504	Cw	3.5 – 4.4	21.9	Clay shale Sandy shale Sandstone	21 – 38 29 – 39 39 – 77
505	Cz C W	7.0 – 8.8	16.7	Clay shale Sandy shale Sandstone	22 – 32 32 – 40 41 – 48
507	W z	5.0	20.1	Clay shale Sandy shale Sandstone	22 – 26 34 – 37 38 – 59
712/1-2 712/1-2- 713/1	Mn	3.8	24.7	Clay shale Sandy shale Sandstone	28 – 37 34 – 65 52 – 80

5. General description of the seismic activity in 2015 – 2018

Hard coal mining leads to disorder of the original rock balance, which is accompanied by dynamic phenomena [6]. The energies of these phenomena depend on the changes the mass rock that take place within the range of exploitation influence. Rock mass movement resulting from exploitation determine the strain-deformation states of the layers overlaying the areas of exploitation, which affects the level of stress in the continuous layers, which constitute a coping for the void areas. Such layers, with suitable large deformations caused, for example, by the gobs, can be a source of very strong seismic phenomena.

One of the parameters describing the magnitude of the seismic hazard is the seismic intensity index $I^0 = E$ / W [J/T] where: E - the sum of the released seismic energy [J], W - extraction expressed in tons [T]. It allows to compare the magnitude of the seismic hazard with respect to: year, seams, mining areas, etc.

The chart (figure 2) shows the trend of the seismic intensity index in relation to its annual average value and the total energy of tremors in the analyzed period divided into individual seams in which mining operations caused the occurrence of rock mass tremors.

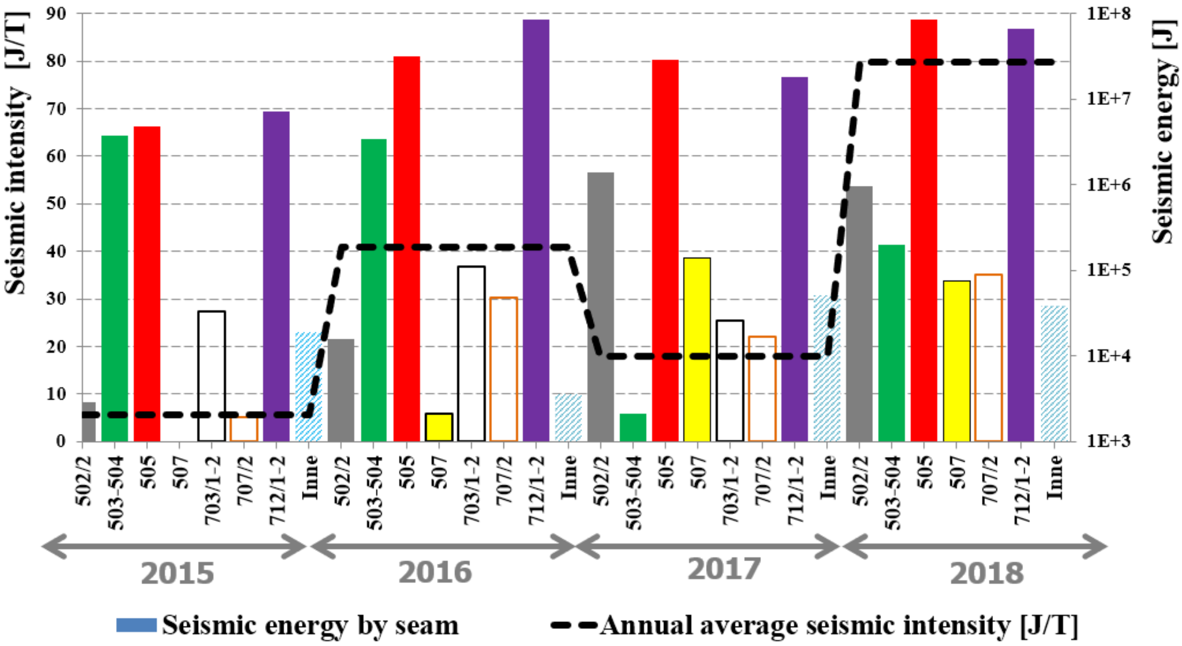

Figure 2. Chart of seismic intensity in relation to its annual average value and the total energy of tremors.

Seismic intensity index for seams 712/1-2, 505 and partially 503-504 every year is much greater than average. The seismic hazard as well as rock bursts hazard in particular seams is determined by diversified geological and mining conditions, including previous operational influences such as leftovers and edges created in neighboring seams.

The sources of high-energy seismic tremors are usually compact, thick layers of durable (resilient) rocks, which in case of the GZW Carboniferous rock mass are sandstones and siltstones (sandy shales). Such layers are colloquially called tremor-generating layers [7].

Recorded tremors characterized are by their considerable distance from the seam in which mining works are carried out. This is associated with the occurrence of thick and strong layers of sandstones in these regions.

6. Characteristics of tremors occurring in the period 2015 - 2018 after which effects were recorded in mine workings

On 17/03/2015 at 16:52:45 in the area of the active longwall C-3 in the seam 503-504 and 503 there was a tremor of energy E = 7.7×10^5J - the epicenter of the tremor was about 55 m in front of the upper part of longwall face an approx. 150 m above the seam. As a result of the tremor in the C-3 longwall tail-gate, on a distance of approx. 40 m from the longwall C-3 face following were observed: floor uplift max. 0.7 m from the side of the south sidewall, slips on the clamps of the ŁP roof support - max. 0.6 m, damage to the welded mesh seal, Valent props tilt, installed in a 20 meter reinforced zone of the working, tilt of three utits of the powered roof support BW 20/41 POz (carried in the C-3a working in front of the C-3 longwall face), scattering of stored material. The crack of the sandstone roof layers of the seams 503-504 and 503 was considered the cause of the tremor.

On 01/04/2016 at 11:20:52 in the area of C-3 longwall completed in December 2015, in seam 503-504 and 503 there was a rock tremor with seismic energy E = 3.1×10^6J - the epicenter of the tremor was approx. 50 m west of the C-3 longwall ending line, approx. 230 m above seam. As a result of the tremor, relaxation of the rock mass with small effects in underground workings was found, i.e. in the C-2 exploration slope and the C-4 transportation slope in the 505wg seam, for approx. 60 m the floor uplift max. 0.8 m, slips on the clamps of the ŁP roof support approx. 0.4 m and, in some cases, minor damage to the seal. The crack of the sandstone roof layers of the seams 503-504; 503 and 504 in the area of the edges of the superstructure built up in seams 502/1, 501/3, 417, 415/2, 413/2.was considered the cause of the tremor

On 17/03/2017 at 19:13:07 in the area of the C-3 longwall, in the 505g seam, there was a rock tremor with seismic energy $E = 1.9x10^6 J$ - the epicenter of the tremor was at a distance of about 40 m from the front of the lower part of the C-3 longwall and about 120 m above seam 505. As a result of the tremor, the coal floor cracked near the crossing of the C-3 longwall head gate with the C-4 transport slope in the 505g seam and dislocation of the rollers on the PT 7 belt conveyor in the C-2 exploration slope. The crack of the sandstone roof layers of the seam 505 and upset balance of sandstone-shale layers lying between the 501/3 and 502/2 seams in the region of the superstructure edges in the seams 502/2, 501/3, 417, 415/2, 413/2 was considered the cause of the tremor

On 16.10.2017 at 16:38:14 in the area of the C-3 longwall, completed in March 2017, in the 505wg seam, there was a rock tremor with seismic energy $E = 8.9x10^6 J$ - the epicenter of the tremor was at a distance of: 130 m from the place where exploitation of the seam 505wg was terminated and about 95 m above seam 505. As a result of the tremor in the C-4 transportation slope located between the longwall entry C-2d and the longwall entry C-3 (the finished longwall C-3) found: local floor uplift to 1.0 m, slips on clamps of ŁP roof support reaching up to 1.80 m, local damages to the welded mesh and in several cases damage of connections multi-element struts with support frames, damage to the sprayed concrete coating made of (shotcrete) in the form of cracks and splinters and total destruction on a section of approx. 20 m. The tremor was classified as stress relief. The crack of the sandstone roof layers of the seam 505 and upset balance of sandstone layers with a thickness of approx. 24m. lying approx. 50m. above seam 505 in the region of the superstructure edges was considered the cause of the tremor.

7. Preparation of digital deposit model for the given area

In order to better visualize the area, a spatial model of this particular mine part was created which contains: exploitation plots, development workings, tremor focal points, floors of coal and sandstone strata. Figure 3 additionally shows a cross-section visualizing the geological structure between seam 505 and 501/3 along the C-3a working.

7.1. Software used for digital deposit modelling

The obtained source materials were developed using the Geolisp software [8]. The system operates in a CAD graphic environment and allows for automation of the most frequently performed works in the field of mining map preparation. The Geolisp program cooperates with the original Jan Białek program - EDN-OPN, thanks to which it is possible to combine the obtained results of calculations of predicted deformations of the mining area and the rock mass with the digital map.

7.2. Activities performed during the creation of the deposit and development model

The following subsections presents the activities carried out during the creation of a spatial model of a fragment of the KWK ROW mine.

7.2.1. Exploitation data import. Files containing parcels data in prof. Białek format were loaded to the AutoCAD drawing with cPrc command (figure 5) [9]. After execution of cPrc command it is required to provide path to the parcel data files. As a result `of the program's operation, the contours of the parcels, created with a 3D polyline and texts with the name of the longwall will be inserted into the drawing. Parcels were loaded into layer with the same name as seam name. Remaining descriptive data were loaded to the drawing database in a form of so-called additional element data. Access to loaded data is available by ePrc command.

IOP Conf. Series: Earth and Environmental Science **261** (2019) 012020 doi:10.1088/1755-1315/261/1/012020

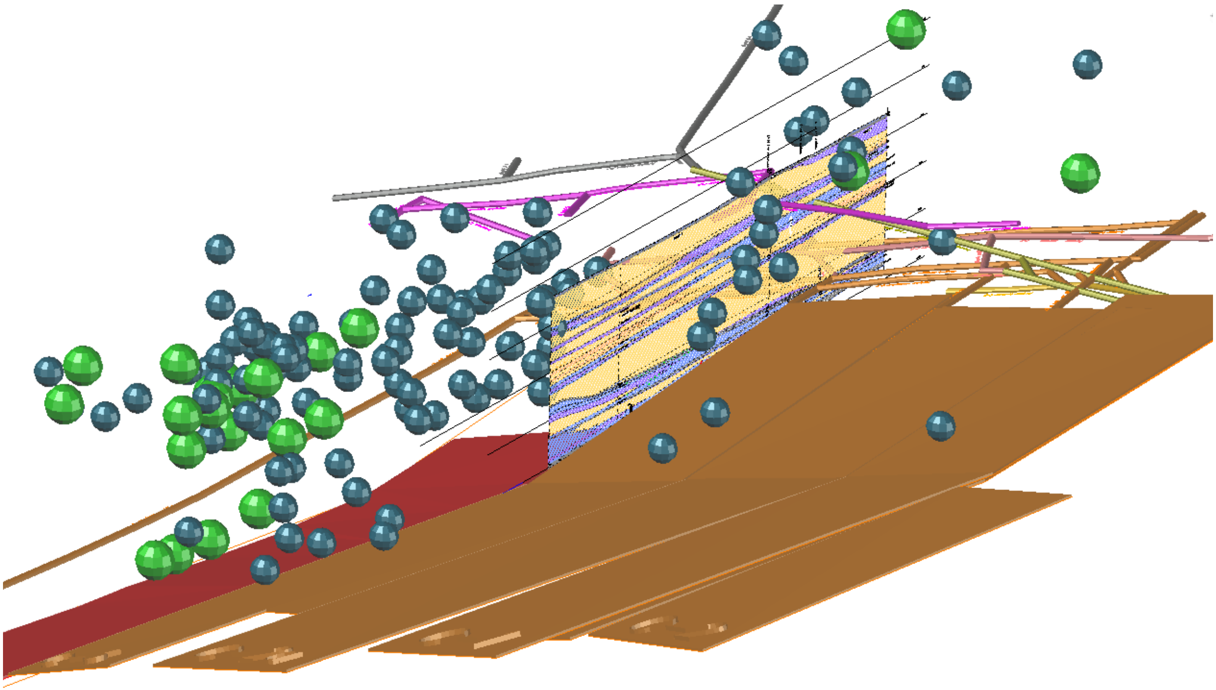

Figure 3. Deposit model containing exploitation plots, development workings, tremor focal points and geological cross-section.

7.2.2. Loading tremor data. With the command rOkWs (draw tremor circles) area of tremors has been selected. Each tremor has been marked on the figure 4 with two circles: first circle represents year of the tremor occurrence while the second one shows tremor energy. Tremors are visualized with circles on 2d surface (figure 4) and with spheres in 3d space (figure 3).

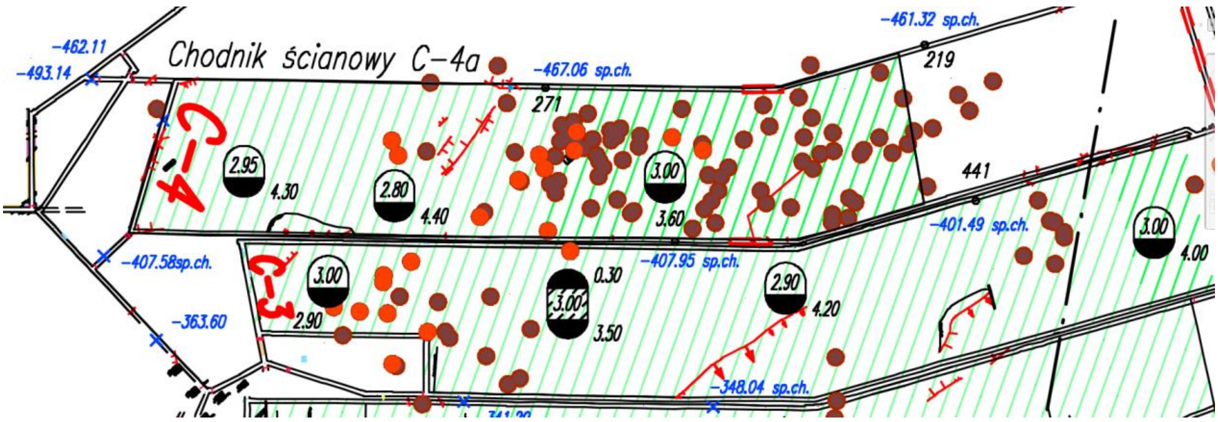

Figure 4. Tremors presented on the parcels background.

7.2.3. Creation of the blocks based on exploitation parcels. Parcel data loaded to the drawing were converted to the solids using the bPrc command (figure 5). Information about surface area and volume of each parcel has been added to the additional data database [10].

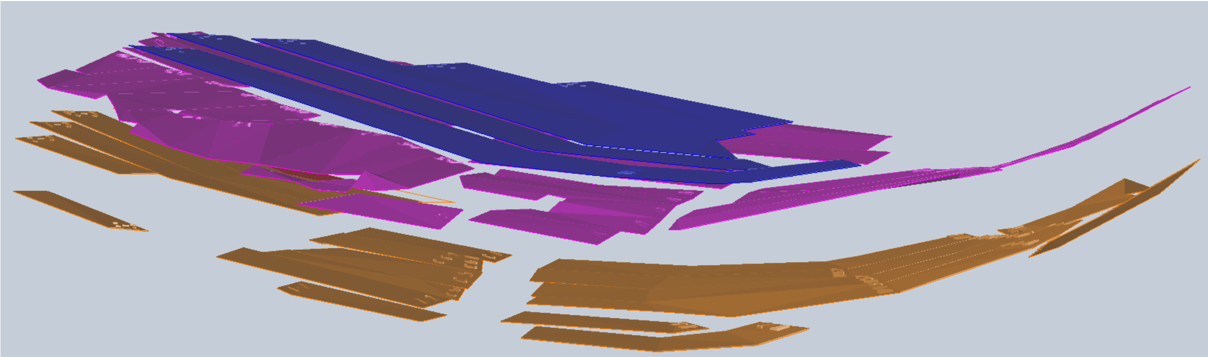

Figure 5. Exploitation parcels presented as 3D solids.

7.2.4. Conversion of working axes into 3D polylines [11]. On the seam 502,503+504, 505, 507 maps and level 400 and 600 maps received from Mine, axes were replaced with 3D polylines using the os3d command (figure 6). Presentation of the workings in 3D space may significantly accelerate work in various departments of the mine. Such model presents spatial relations between elevation points measured in individual workings.

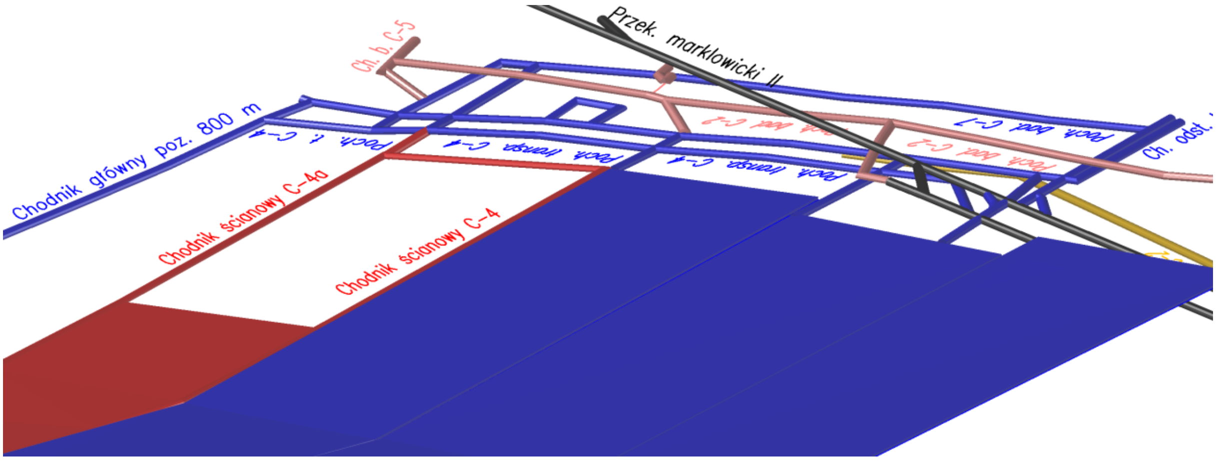

Figure 6. Workings presented as 3D solids.

Os3d application allows not only replacement of the axes into 3D polylines but also allows for verification of elevation points correctness, based on which elevation of each axis is determined. In the dialog window which pops-up after program execution information about admissible distance between points, admissible height difference, and admissible distance from points to axis (up to this distance, points will be taken into account when calculating the height of the axes) can be added by filling suitable fields. Additional functions of this application:

- checking if points are used more than once;
- searching for axes with not height assigned;
- averaging axes intersections;
- solids creation based on axes;
- description of intermediate points;
- presentation of points which are used in a given axis;

IOP Conf. Series: Earth and Environmental Science **261** (2019) 012020 doi:10.1088/1755-1315/261/1/012020

- taking into account the intersection with the side walls - points lying close to the axis will not be included if there is a sidewall line between them and the axis (in practice, this should eliminate accidental inclusion of points, e.g. from a crosscut in the working axis);
- insertion of intermediate points - the program will insert additional points on the axis, in the locations of elevation datapoints.

The coordinate of axis endpoints program calculates based on neighboring points of the matrix. In the case when there are no points near the end of the axis, the axis will not be converted to a 3d polyline. Elevation datapoints should be located near intersections and at the ends of the axis.

7.2.5. Creating a TIN surface showing a part of the seam 505 floor. The TIN surface consists of triangles forming an irregular network [12]. Points that are the vertices of triangles have flat coordinates and a numerical parameter, e.g. aquifer, seam floor, sulphation, etc. The surface can be visualized by isolines, a hypsometric map or a grid of triangles.

The surface imitating the floor of seam 505 was created using the atr2pkt program (figure 7). It allows to create a floor surface based on the following map objects: boreholes, shafts, matrix, elevation points and analysis blocks. The operation of the program can be narrowed down to a specific set of objects. It should be selected using the "Which objects" database whether the surface will be created based on: all objects, objects assigned to the current seam, objects assigned to the current object, indicated manually. In addition, it should be chosen based on which attributes block the surface will be created (database “Which attribute”).

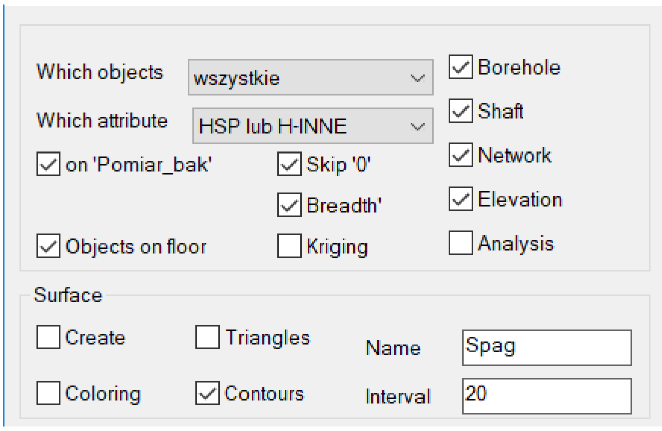

Figure 7. Dialog window of the program creating seam floor based on elevation datapoints.

With the Krig command, the created surface has been smoothed and extended to the indicated range using the optimal prediction method. Smoothing the surface adds points to the ordinates set by the program, thanks to which the contours are smoothed and do not overlap. Extrapolation beyond the surface area is made based on statistical trends observed within the surface.

As a result of the program operation, points were added to the surface, the surface was smoothed and extended to the floor area of the 505 seam floor. Points were obtained which Z-value corresponded to the difference in the distance between seam 505 and the sandstone. To obtain the surface showing sandstone floor to the floor surface, these points were added using the opRzut command (figure 8).

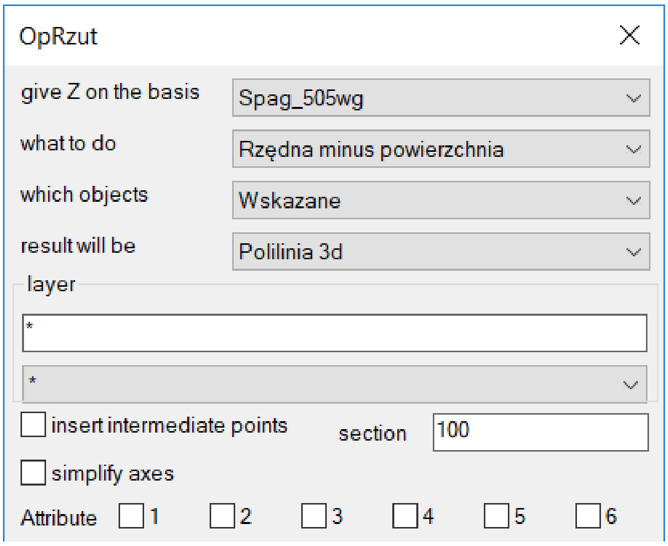

Figure 8. Dialog window of the program allowing projection of the objects on TIN surface.

6. Summary

Among others following factors influencing the occurrence of rock bursts hazard in the KWK ROW Site Marcel should be included: significant deposit depth, saddle and jejkowice seams located next to strong sandstone and sandy shales layers, occurrence of tectonic and sedimentary disturbances causing leftovers and unmined areas of the deposit as well as basin nature of the deposit (the Jejkowice and Chwałowice Basins). These are elements of the deposit that cannot be changed in any way.

Only the proper recognition of the geological structure of the deposit allows for designing its exploitation, which will limit the possibility of rock bursts in the maximum way [13]. However, there are also areas where, despite a properly designed mine plan, the seismic hazard, and thus also the threat of rock bursts, occurs at a relatively high level. In this case, it is helpful to implement active rock bursts prevention, which used in the seam or surrounding rocks and in the proper and adequate to geological and mining conditions will allow to significantly reduce the rock burst risk.

The last limitation element of the rock bursts are organizational activities. Determination of “Special rock burst zones” in areas with high rock bursts hazard, allows for limitation of people presence in those areas. Combining of above factors will allow for safe work in bump hazardous areas.

In order to assess the stability of the pillar and located in it haulage, transportation and ventilation workings in the part "C" of KWK ROW Site Marcel and the part "Z" of KWK ROW Site Jankowice, digital deposit model has been created, which took into account planned and carried out exploitation.

Model includes: exploitation parcels, workings, tremor focal points, seem and sandstone floors. Digital deposit model allows for spatial visualization of objects from which it was constructed. Quick access to the information contained in the model, allows for optimum and safe production and mining works planning [14]. Thanks to information of mining hazards it also increases work safety.

Editing of the data implemented in the model causes its updating, which allows to assess the impact of the introduced changes on the existing model.

The numerical model of the deposit was used for geomechanical analysis of the rock mass in selected regions of the KWK ROW. The mapped geometry of selected seems, and the longwalls run in them has been digitized with tetrahedral finite difference zones and introduced into the FLAC3D program. In the discretized model, after adopting boundary conditions and material properties, progressive mining exploitation was simulated, which allowed to determine the stress states in the analyzed rock mass.

IOP Conf. Series: Earth and Environmental Science **261** (2019) 012020 doi:10.1088/1755-1315/261/1/012020

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