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Impact assessment of induced seismicity on surface in conditions of Czech part of Upper Silesian Coal Basin (OKR)

Abstract

Mining exploitation of hard coal deposit is attended by induced seismicity. This seismicity can be manifested negatively in underworkings (rock burst) and on surface (Earth's surface vibration). The paper describes present method assessment of induced seismicity on surface in conditions of Ostrava-Karvina coalfield. The assessment comes out from data of regional seismic network. The impact assessment of induced seismicity is provided according to Czech technical standard (CSN 73 00 40). Impact of induced seismicity can be affected (amplification or attenuation) by interaction of number of factors. The basic factors are geological properties of rock mass having influence on propagating seismic waves to Earth's surface. In the paper authors for instance describe some of these factors, which can probably have a significant impact in conditions of Upper Silesian Coal Basin (OKR). The paper gives a brief summary of work done in this field and the work planned for the future.

1. Introduction

In Upper Silesian Coal Basin several tens of thousands of weak induced seismic activities are registered annually, but there are only several tens of energetically strong activities (fig. 1.1).

Fig. 1.1. Geographic location of Upper Silesian Coal Basin within frame of territory of Czech Republic (OKR)
Rys. 1.1. Lokalizacja geograficzna Górnośląskiego Zagłębia Węglowego na terytorium Republiki Czeskiej

The fact if a seismic activity is accompanied with vibration of earth's surface (i.e. trembling of surface structures and items inside of them, vibrations unpleasantly sensed by people and animals – such as swinging, rattling of door and window panes, chinking of glasses and dishes, swinging of suspended items or falls of small unstable items, etc.) is influenced by a number of factors, it is particularly a released seismic energy and location of seismic activity (observed effects on the surface are usually smaller with increasing distance from epicenter and its bigger depth). Among significant factors there are particularly physical mechanical properties of environment between epicenter of mine tremor and location of observation (geological and hydrogeological conditions) and properties of subsoil of the structure (depth of underground water below the foundation bottom, closeness of tectonic zone, sliding zone, etc.). Manifestation on the structure is affected by its character, method of its foundation and construction (e.g. structure is founded with or without foundation slab, its construction), condition of structure (maintenance, age) or also degree of previous damage, etc. Impact of induced seismicity can also be often mistaken or combined with other unwanted effects – in addition to defects in foundation of structure, effects of different properties of subsoil and bedrock, effects of shallow or fluctuating depth of underground water level; there can also be e.g. repeated impact of seismic bursts which is caused by artificial sources, e.g. automotive traffic on close road, train passing on nearby railroad track or some other industrial seismicity; or there is a damage caused by mining activities but as a result of surface subsidence by undermining.

2. Natural conditions of Czech part of Upper Silesian Basin

2.1. Carboniferous rock formation

Upper part of Carboniferous rock formation in Karvina part of Czech part of Upper Silesian Basin, where exploitation of coal seams is taking place, is created by beds of Doubrava, Sucha and Saddle of Karvina strata and Poruba beds of Ostrava strata.

Karvina strata represents a continental coal-bearing molasa in Upper Silesian Coal Basin (middle and upper namur, Westphal A). Lihtologically it is characterized by a distinct cyclic structure. The whole continental coal-bearing molasa represents independent megacycle mainly with coarse-grain sediments and thick seams at the base – saddle and lower Sucha beds, and with not very thick cycles with fine-grain sediments (Doubrava and upper Sucha beds) in upper part of strata. Solid conglomerates and sandstones occur, in the structure of rock strata between coal seams in the Karvina strata, at a significant degree (Dopita et al. 1997).

In Upper Silesian Coal Basin, Ostrava strata represents a paralic load-bearing molasa (lower namur). Poruba beds represent upper part of this strata. Lithologicaly they are characterized by a distinct cyclic structure. Particularly siltstones and mudstones form structure of the rock strata between coal seams in Ostrava strata. Share of sandstones and conglomerates compare to some other lithostratigraphical units is a significantly smaller (Dopita et al. 1997).

From the standpoint of tectonic structure, the Czech part of Upper Silesian Basin does not form unified and homogeneous unit. Territorially it can be divided into two fundamental units separated by the Orlová structure. Described works are implemented in the Karvina Partial Basin (hereafter as KPB), which is located eastward from the Orlovská structure. A frame of tafrogen structure of KPB is created by fundamental subsidence with amplitude mostly about tens to hundreds of meters combined with horizontal strike-slip faults. There are two entirely dominant directions – longitudinal N-S to NNE-SSW or NNW-SSE and transverse direction oscillating around W-E direction. By a nature of its displacement, the number of subsidence is approximate to rotation faults of hinged type. Small (seam) faults mainly of subsidence type, with considerably variable genesis and orientation, are inserted into this fundamental frame. Furthermore there are also shift faults in the Karvina area. There is a zone of flat shifts dipping (10–30) predominantly southward at some places inter-layered, which are approximately parallel with transverse subsidence (Dopita et al. 1997). Figure 4.1 shows fundamental tectonic structure of KPB on Carboniferous relief.

2.2. Covers of Carboniferous

The thickness of sediments, generally called as cover, is ranging in assessed area from couple of meters (with occurrence of Carboniferous inliers) in medium part, up to several tens and hundreds of meters particularly in dependence on morphology of buried Palezoic relief (see fig. 4.3).

In KPB the cover is formed in its upper part particularly by quaternary sediment formation of the middle Pliocen. These formations are represented by paleoclimatically and lithogenetically various glacial and interglacial sediments of Elster and Sals sedimental denudation and soil-forming cycle (Dopita et al. 1997). Thickness of these sediments reaches from one meter up to couple of tens of meters.

Pre-quarter sediments create second distinct part of Carboniferous cover and they are represented by sediments of Carpath and Baden. Particularly Baden sediments are important. They form basal coarse-grained unclassified clastics, which were deposited into considerable depressions of pre-Baden relief. These clastics are sharply covered by monotone strata of gray lime sea clays creating their impermeable roof (Dopita et al. 1997).

Two types of hydrogeological environment can be important for investigated problem from hydrogeological standpoint. First type is an aquifer rock of Quaternary sediment or aquifer rock originating in antropogennous embankments of cover. Due to genesis and nature of aquifer rock sediments, in many cases these aquifer rocks are not developed continuously in area of large territories. However the level of underground water of these aquifer rocks is in number of cases ranging in shallow depth under the surface (1–3 m) – see chapter 4 and fig. 2. Second type is an aquifer rock bounded to clastics of lower Baden, which is hydraulic system with confined surface, nowadays strongly impacted by antropogen activities (Dopita et al. 1997).

3. Contemporary assessment method of seismic impacts on surface

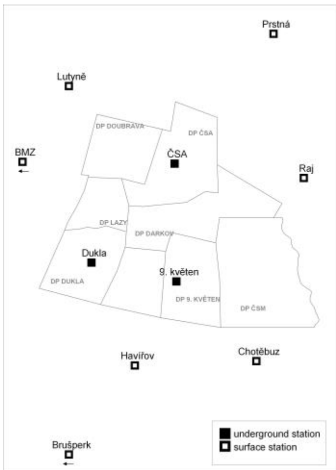

Fig. 3.1. Map of seismic station of SP network
Rys. 3.1. Mapa stanowisk sejsmologicznych

Continuous measuring and assessment of seismic effects of induced seismicity on surface is enabled by network of seismic stations of Seismic Polygon (SP) of OKD, DPB, a.s. in Paskov. The basic task of SP is continuous monitoring, particularly of strong induced seismic activities in the system of rockburst measure in OKR. SP is a regional seismic network consisting of seven surface and three underground three-component stations, which are spread around Karvina part of OKR (see fig. 3.1.) Thanks to hardware and software equipment of SP, results of registration can be also used for determination of seismic effects on surface structures. One vertical and two horizontal sensors (N-S and E-W) with exact orientation allow determination of complete vector of vibrating movement (displacement, velocity, acceleration) on each of SP station. Sensors register a velocity of vibrating movement as a basic record, acceleration is obtained by a numeric derivation of signal and displacement then by a numeric integration of signal. Values of ground velocity at stations and maps are determined from records. Isolines are processed by the method of standard linear interpolation from regular point array by our own computer software.

Computer software allows a processing of array of maximum amplitudes for defined seismic activity but also for selected group of seismic activities (e.g. selection of intensive seismic activities in longer time period e.g. in one year), in such case maximum values from the whole file of activities are determined. Maximum values, of amplitudes of whole point array without any reference to selected density of point array (for monitored area of approximately 8×10 km is commonly used array of 40×40 points, i.e. points at the rectangle of 200×250 m), are further specified up to the density of 5×5 m for determination of absolute maximum which is located near epicenter of mining tremor.

An example of map with isolines of ground velocity for seismic activity is shown on figure 3.2. Presented isoline array is very complicated which is a demonstration of complicated mechanism of epicenter origin.

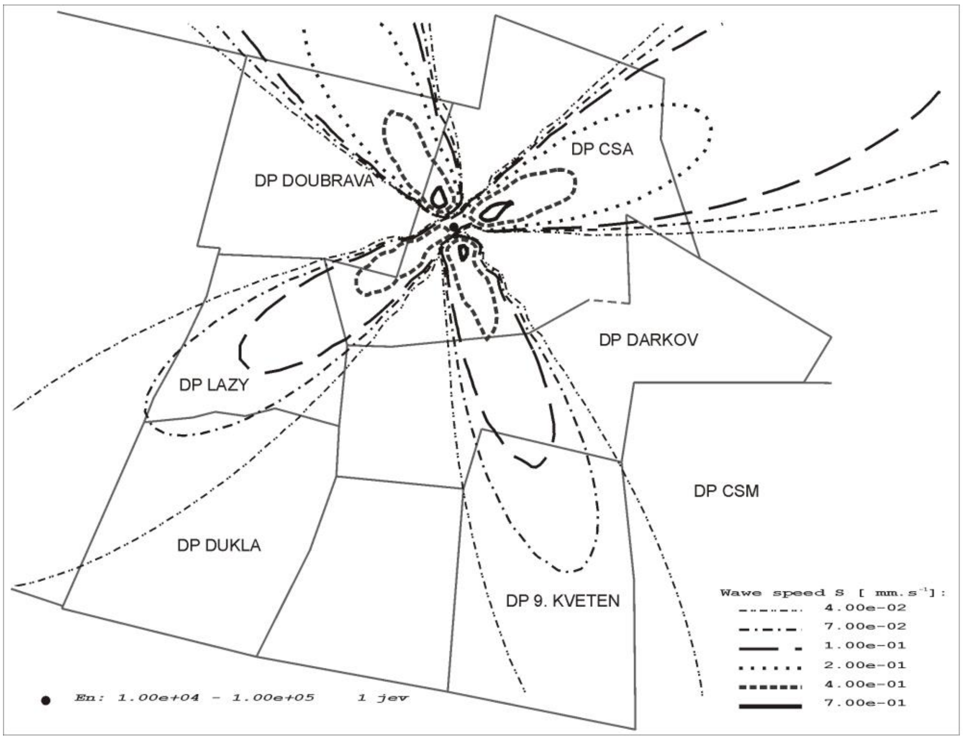

Fig. 3.2. Map of isolines of ground velocity (values of isolines were optimized by computer program) for mining tremor on 18.6.2005, which epicenter was located in the area of CSA Mine
Rys. 3.2. Mapa izolinii prędkości drgań gruntu, optymalizowanych programem komputerowym, dla wstrząsu z dnia 18 czerca 2005 r., którego epicentrum zostało zlokalizowane na obszarze górniczym Kopalni CSA

The most precise data of calculated array of ground velocities are near monitoring points included into the calculation. In more distant areas these values can differ particularly due to application of simplified geological model of the Karvina area, simple model for determination of epicenter mechanism and local changes of different geological factors. In compliance with requirements of standards, it is necessary to monitor and assess actual seismic effects for every seismic activity and concrete location of expected activities.

Table 3.1 gives a summary of number of registered stronger induced seismic activities (selection from SP database) in years 2002–2005. Table shows also a maximum value of seismic energy and maximum value of ground velocity in the epicenter calculated from records of SP stations for these induced seismic activities.

Table 3.1.

Numbers of registered strong induced seismic activities in years 2002–2005

Tabela 3.1.

Ilość wstrząsów zarejestrowanych w latach 2002–2005

Year	**Number of activities with energy from $5{,}0 \cdot 10^4$ [J]**	**From that, activities with energy from $1{,}0 \cdot 10^5$ [J]**	**Maximum value of seismic energy [J]**	**Maximum value of ground velocity in epicenter [$mm \cdot s^{-1}$]**
2002	83	45	$6{,}0 \cdot 10^6$	4,7
2003	83	40	$2{,}3 \cdot 10^6$	3,5
2004	72	33	$6{,}4 \cdot 10^6$	7,5
2005	93	44	$4{,}0 \cdot 10^6$	6,5
Total	331	172	$6{,}4 \cdot 10^6$	7,5

Overall it can be said, that an intensity of seismic effects caused at surface by a mining seismicity depends on many parameters and particularly on the following:

- mechanism of mining tremor epicenter,
- size of emitted seismic energy,
- epicenter distance and depth of mining tremor epicenter,
- structure of rock mass through which seismic waves propagate and local geology in location of monitored manifestation.

4. Geological factors impacting effects of induced seismicity on surface

For further investigation in conditions of KPB we included, among fundamental geological factors which can impact a size of induced seismicity effects on surface, also the following:

- Structural tectonic structure of Carboniferous rock mass.
- Underground water level.
- Hydrological conditions.
- Thickness and character of cover Carboniferous formations.

The structural-tectonic structure was included in fundamental parameters because close occurrence of active fault tectonics can impact action of induced seismicity effects. Actions of induced seismicity on surface can be both amplificated or attenuated. Accessible groundwork on tectonic structure of the Karvina Partial Basin was collected from published papers and geological documentation from individual mines. The structural tectonic map on level of Paleo-relief of Carboniferous compiled by Aust (Aust in Dopita et al. 1997) was simplified and modified for the area of Karvina Partial Basin based on data founded during exploitation and mining work done in years 1997–2005 (fig. 4.1).

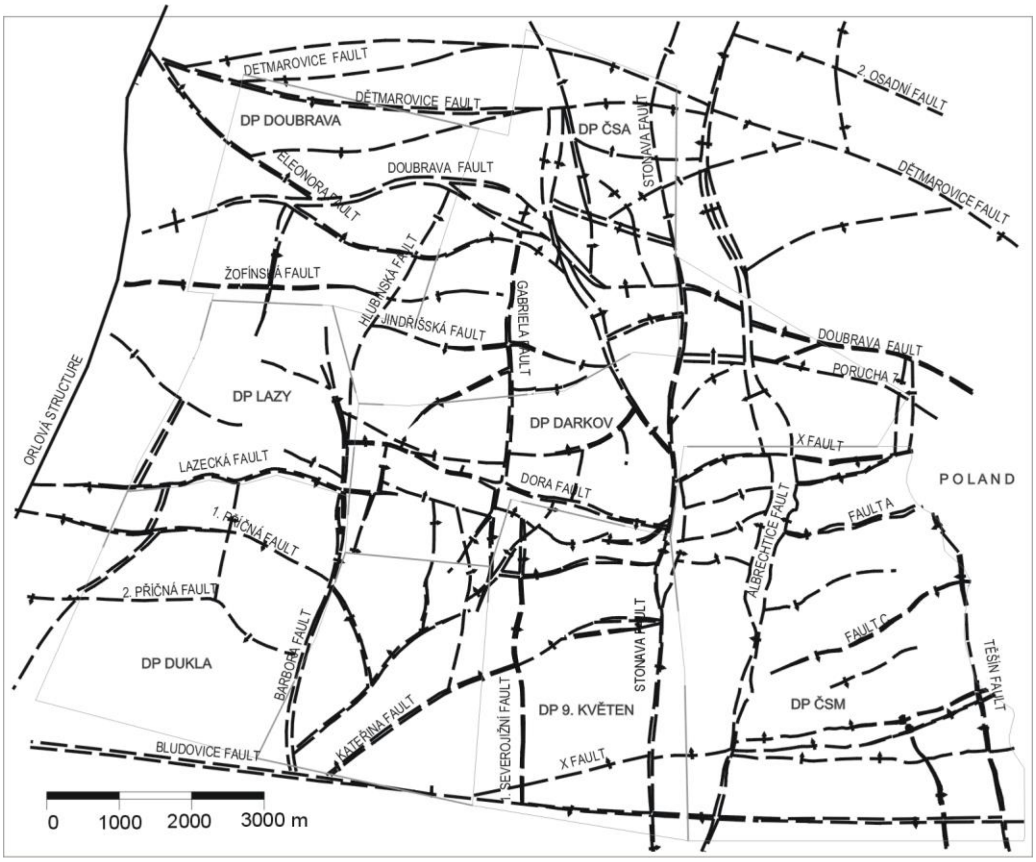

Fig. 4.1: Fundamental structural tectonic structure of the Karvina Partial Basin on level of Carboniferous relief

Rys. 4.1. Podstawowa sieć uskoków w stropie utworów karbońskich w Zagłębiu Karwińskim

Underground water level represents another important parameter from the standpoint of amplification or attenuation of induced seismicity effects on surface structures, which is documented in seismically active areas. Data on depth of underground water level were selected from hydrogeological exploitations and studies processed up-to-date for OKR mines and they were compiled into synoptic maps (fig. 4.2). Underground water levels in selected parts of mining areas in the Karvina Partial Basin in individual time horizons, when they were measured, are shown in compiled map. Continuous monitoring of underground water level is carried out only at very small number of locations and was not included into this output. Compilation of the curve of underground water level in the whole area of KPB is very complicated particularly from the following reasons:

- noticeably variable blanket occurrence and often a mutual discontinuity of individual aquifer rock environments (antropogen aquifer rocks, fluvial or galcigenous aquifer rocks),
- locally distinct dependence of underground water level condition on infiltration degree of surface water and season,
- frequent changes of underground water level dependent on development of subsidence basinkettle depressions in individual mining areas,
- formation of new aquifer rock environments through reclamation interferences (antropogen aquifer rocks).

Individual measurements of depth of underground water level in individual structures (wells, boreholes) are, between each other, taken in small parts of assessed territory in dependence on assessment of given partial area of mining area and so they cannot be correlated from the viewpoint of time. From the above-mentioned reason, their full-area output for the whole Karvina Partial Basin is very complicated. Presented synoptic map of depth of underground water level must be considered as rough tool and for future measurements it must be further modified or possibly the depth of underground water level in specific locations of placed seismological stations must be found.

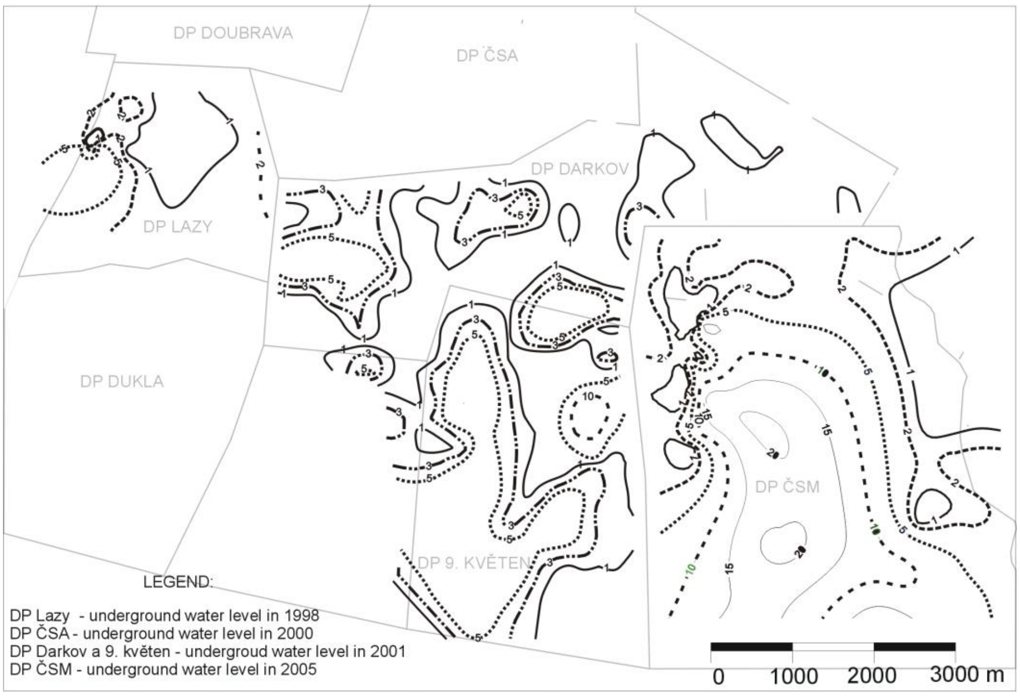

Fig. 4.2. Synoptic map of depth of underground water level [m] in selected parts of mining areas of the Karvina Partial Basin.
Rys. 4.2. Mapa synoptyczna głębokości położenia poziomu wód gruntowych [m] w wybranych częściach obszarów górniczych w Zagłębiu Karwińskim

Hydrological conditions – occurrence of large water accumulations on surface can effect a size of induced seismicity impact on surface. Blanket occurrence of significant surface water accumulations was compiled based on available orthophotomap created from aerial photographs of the terrain which were implemented for the whole Karvina Partial Basin in 2002. Significant waterscapes and watercourses were outlined and highlighted on the base of orthophotomap of the Karvina Partial Basin.

The thickness and geological structure of cover formations of coal-bearing Carboniferous represent a fundamental factor, which can affect possible seismic impacts on surface structures due to their different natural properties. Up-to-date available data on thickness and character of cover formations stored over the time of deposit extraction in the Karvina Partial Basin were collected for our purposes and saved in the form of database. The output is an isoline map of Carboniferous cover thickness. At the first stage, the map of isolines of Carboniferous cover thickness was compiled from data of deposit exploitation boreholes, existing vertical workings and mapped Carboniferous inliers. Further detailing was done by introduction of other data from which the thickness of Carboniferous cover can be used (old mine – vertical as well as inclining and exploitation geological works of non-deposit character). The map of thickness isolines of Carboniferous cover is shown on figure 4.3.

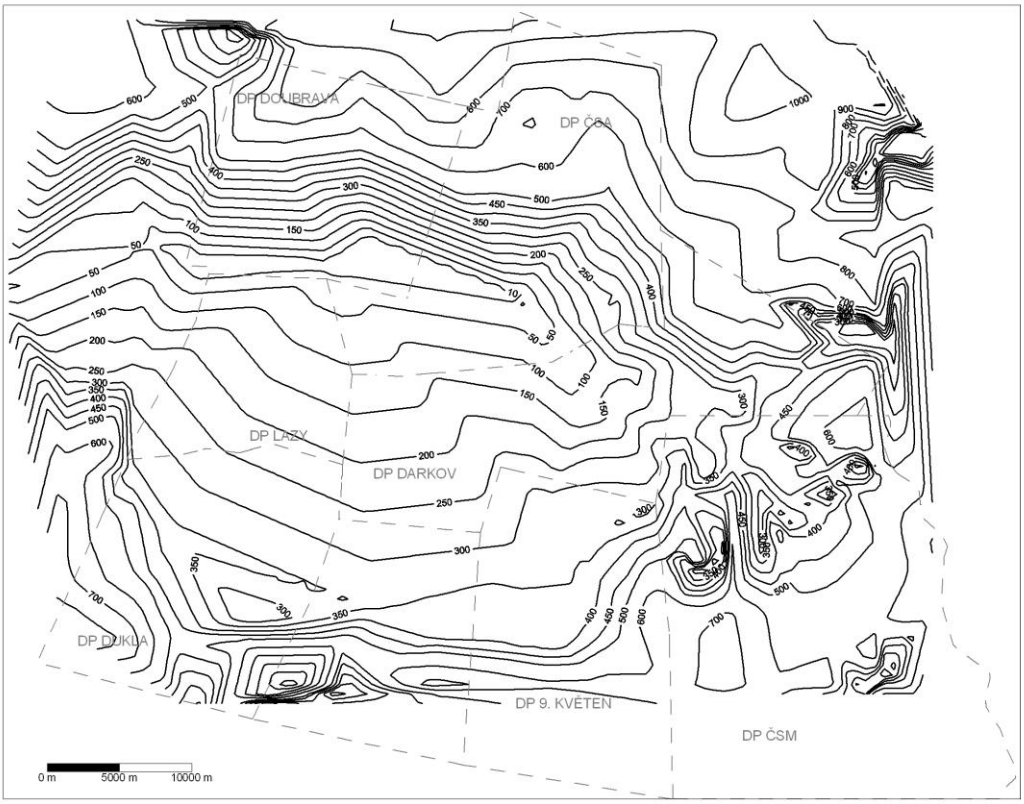

Fig. 4.3. The map of thickness isolines [m] of Carboniferous cover in Karvina Partial Basin
Rys. 4.3. Mapa izolinii grubości nadkładu utworów karbońskich w Zagłębiu Karwińskim

From the map of thickness isolines of Carboniferous cover, it is obvious that a territory with small thickness and small changes of sediment cover runs in west-east direction through the central part of Karvina Partial Basin (with exception of its most eastern part). In contrast to that, in north-south direction in the central part there are big changes in sediment thickness from a rise of Carboniferous formations to the surface up to a thickness over 700 m in north part of the area. At the first approach, results of seismicity manifestations will be compared only with known thickness of Carboniferous cover. At the following approach, it will probably be necessery to consider an individual assessment of cover formation thickness according to their different natural properties.

5. Conclusion and plan for future progress

Because we are aware of inaccuracies of interpolated results of ground velocities, in the following period we want to confront these results with results of other three-component surface seismic stations. In order to qualify an impact of local geological conditions on surface vibration (amplification or attenuation), it is necessary to obtain the most possibly detailed information on geological and hydrogeological conditions in interested area – the Karvina Partial Basin.

Values of ground velocities obtained from SP data and from surface measurements of other stations in the Karvina Partial Basin will need to be analyzed, in dependence on geological and hydrogeological conditions in locations of these seismic stations and in locations of traveling of seismic signal from its source to the surface, for confirmation of assumption that geological and hydrogeological conditions affect the seismic impact.

In addition to geological factors, a significance of epicenter origin mechanism on shape of isolines in small epicenter distances will need to be assessed, from the practical standpoint, at the compilation process of isoline maps of ground velocities. It shows that this parameter can significantly influence calculated values for the most intensive manifestations.

Further analysis of individual factor effects on induced seismicity impacts can be focused only on certain territories of the Karvina Partial Basin. It depends on existing or planned development according to valid zoning documentation of individual municipalities.

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Ocena wpływu sejsmiczności indukowanej na powierzchnię w warunkach czeskiej części Górnośląskiego Zagłębia Węglowego

Eksploatacja złóż węgla kamiennego generuje sejsmiczność. Zjawiska sejsmiczne uwidaczniają się w sposób negatywny w wyrobiskach podziemnych w postaci stąpnięć, i na powierzchni ziemi – w postaci drgań. Artykuł omawia aktualne metody oceny wpływu sejsmiczności indukowanej na powierzchnię terenu w warunkach zagłębia ostrawsko-karwińskiego. Ocena ta oparta jest na danych zarejestrowanych przez sieć sejsmologiczną. Ocena oddziaływania została przeprowadzona na podstawie czeskich standardów ujętych w normie CSN 73 00 40. Oddziaływanie zjawisk sejsmicznych na powierzchnię jest zniekształcone wpływem wielu czynników. Do podstawowych należą właściwości geologiczne ośrodka. Autorzy opisują kilka z nich, które mogą mieć istotny wpływ w warunkach pomiarowych. Artykuł jest krótkim omówieniem wykonanych prac oraz prac planowanych w przyszłości.

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