GOSPODARKA SUROWCAMI MINERALNYMI

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Linear discontinuous deformation of A4 highway within mining area "Halemba"

Introduction

Usage and exploitation of hard coal seams in the USCB meet more and more restrictions related to changes of operational function of the surface. One of such restrictions is construction of new transport routes, especially roadways, within the areas endangered by discontinuous deformations (Kotyrba 2006; Kowalski 2005, 2007; Popiołek, Pilecki 2005). A4 highway in the Upper Silesia crosses mining areas of mines on the long section. Within its section crossing southern districts of Ruda Śląska the highway is located within the mining area of Halemba mine. It is also where the parking place – MOP Halemba-Wirek is situated. From the southern part (MOP Halemba) the region incises with a deep excavation to carboniferous rock formations forming a local dome. Situated in the northern part parking place MOP Wirek was constructed on the level of original ground surface. The highway runs here in the shallow excavation in weathered carboniferous formations. Before the roadway was constructed an intense exploitation of many coal seams had been conducted. Within the section from km 325+500 to 325+600 of the highway the exploitation was not conducted in principle with regard to occurrence of tectonic dislocations. During its construction (2003–2004) the highway was influenced by exploitations conducted with roof fall mainly in three following seams: 415/1, and 501 (in the north) and 416 (in the east). Depths of exploitations changed from 650 m to 812 m. Thicknesses of exploited seams have changed within the scope from 2.0 to 3.5 m. Influences of the above mentioned exploitations appeared on the surface as discontinuous deformations and resulted in damages of both roads of A4 highway. Because of presence of tectonic dislocation within this area the genesis of damages has

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become the reason of discussion between representatives of mines and the investor, as well as the subject of scientific polemics.

1. The characteristic of deformations

In the year 2005, less than one year after the road of the A4 highway had been completed, within the section from km 327+524 to 327+548 such discontinuities as fissures and stages as well as structures consisting of them occurred within its roads. The section where the above mentioned discontinuities occurred is located within the area of parking place Halemba-Wirek. In the area adjacent to the highway and parking place Halemba discontinuities were noticed earlier. They occurred in the forest area to the south of parking place Halemba and within the area of parking place Wirek (to the north of the road of the highway). The damages of the A4 highway in km 327+524 – 327+548 (respectively fig. 1.1 and 1.2) arose before August 2005, first as roadways folding, but later they converted into stages and fissures.

Fig. 1.1. Discontinuity on southern roadway of A-4 – direction Kraków

Fig. 1.1. Nieciągłość na jezdni południowej A4 kierunek – Kraków

The increase of folding altitude along a roadway of A4 geodetically measured from May to August 2005 amounts to:

— on the southern roadway (direction Kraków) 11–14 mm,

— on the northern roadway (direction Wrocław) 17–18 mm.

At the end of August 2005 on the southern roadway of the A4 folds converted into two fissures with their widths from 1–2 cm each. Directions of discontinuities were diagonal to the highway axis with their angles of about 66° (SW-NE). On their continuation within the area outside the roadways there could be found fissures with their width from 4–5 cm and stages of an average height of 7 cm and throw to the East (fig. 1.3).

Fig. 1.2. Discontinuity on northern roadway of A-4 – direction Wrocław

Fig. 1.2. Nieciągłość na jezdni północnej, kierunek – Wrocław

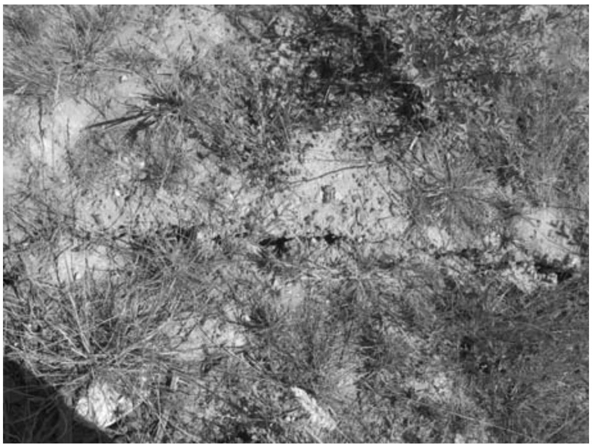

Fig. 1.3. Fissure in soil at place adjacent to roadway A4 from North (Wirek parking place)

Fig. 1.3. Szczelina w terenie na północ od autostrady A4 (MOP Wirek)

Earlier in the year 2003 during conducted monitoring, in the forest area to the south of roadway the occurrence of discontinuities was noticed. There were three parallel wide fissures located 15–20 meters off, with their directions SW-NE. Their lengths amounted to about 100 m, widths to 0.5 m and depths to 1.5 m (fig. 1.4). Signs of these continuities were also visible on the slope of excavation for Halemba parking place construction.

Within the area of parking place being constructed (after the completion of roadway of the A4) in May 2005 after abundant rain, there occurred discontinuities in form of hollows (trench alongside underground fissure) accompanied by sinks with their dimensions of about 2 meters (fissure chutes). Locally, in the near-surface soil layer fissures similar to the one from the fig. 1.3 could be noticed.

Fig. 1.4. Discontinuity of soil surface in forest to South from roadway and parking place Halemba (fot. M. Grygierek)

Fig. 1.4. Nieciągłości w lesie na południe od autostrady i MOP – Halemba (fot. M. Grygierk)

2. Geological conditions

In the image of detailed geological map of Poland in the scale 1:50 000 edited by PIG within the area of parking place carboniferous rocks expose on the surface (fig. 5). However from drillings conducted for needs of geological-engineering documentation it results that from the roadway of the A4 highway to the north in the direct bed quaternary formations can be found. Their thickness varies from zero in the area of roadway to about 20–30 cm in the area to the north of parking place in the Kochłówka river valley where they occur in form of fluvioglacial grounds such as boulder clays and sands (fig. 2.1–2.2). From the stratigraphic

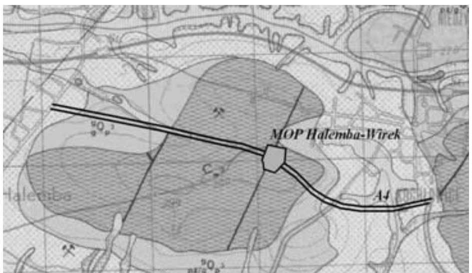

Fig. 2.1. Location of parking place Halemba – Wirek on geological map

Fig. 2.1. Lokalizacja MOP Halemba-Wirek na szczegółowej mapie geologicznej

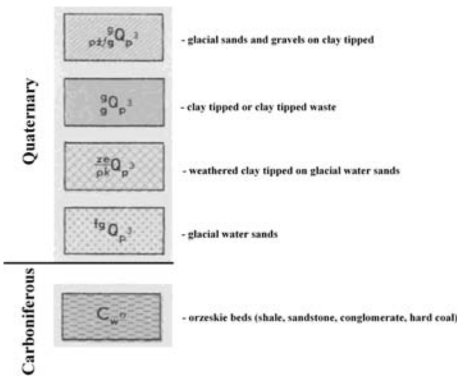

Fig. 2.2. Legend to geological map

Fig. 2.2. Legenda do mapy geologicznej

point of view roof carboniferous layers are formed by Orzeskie beds. In carboniferous formations there can be distinguished about twenty hard coal seams (Rudzkie and Siodłowe beds) depositing alternately in siltstones and sandstones layers. The roof of Orzeskie beds within the parking place is cut by a fault with SW-NE direction. The direction of the fault throw is not indicated on the detailed geological map (fig. 2.1).

On the maps documenting hard coal deposit in the area of parking place there are noticed two faults named fault III and IV, with their throws respectively 20 and 10 m (fig. 2.3). To the north (outside parking area) the size of throws of these faults increases.

Fig. 2.3. Location of parking place Halemba-Wirek on map of overburden thickness (according to geological documentation of coal deposit)

Fig. 2.3. Usytuowanie MOP-u Halemba-Wirek na mapie miąższości nadkładu (wg mapy geologicznej nadkładu z dokumentacji złoża węgla)

According to those data Fault III occurs in km 327+450. Fault IV occurs in km 327+710. Both faults throw the strata to the East. Inclination angles of faults surfaces vary from 65° to 83°. Both faults terminate their ways to the south within the area of Kłodnickie faults.

3. Mining exploitation

Before the highway construction, in the years 1947–2003, mining exploitation of 15 seams (16 layers) mainly with roof fall was conducted within the investigated area. Because of longitudinal course of fault zones the exploitation was concentrated to the north (part F) and east (part H) of the zone between faults III and IV. In the region km 325+500 – 325+600 of the highway mining exploitation was not conducted. During the highway construction (years 2003–2004) the surface was influenced by exploitations with roof fall in three seams

415/1 and 501 (in the west) and 416 (in the east). Depths of exploitations were in the range from 650 m to 812 m. Thicknesses of exploited seams varied from 2.0 to 3.5 m (fig. 3.1).

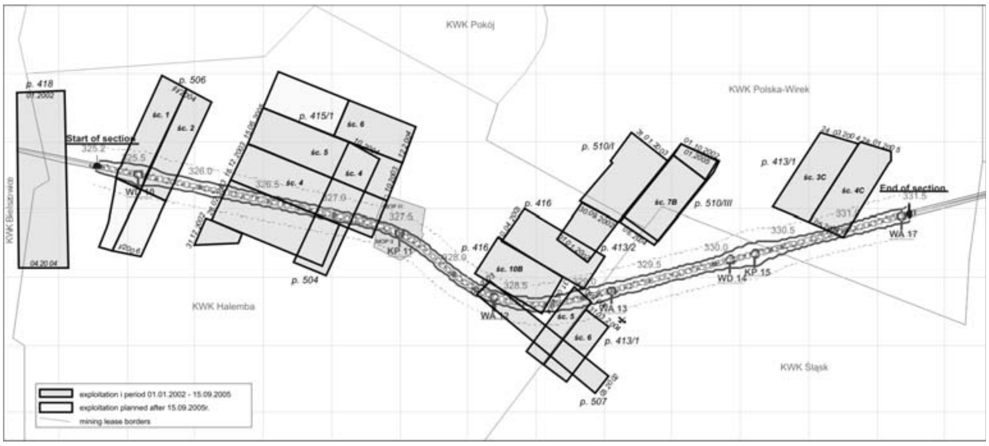

Fig. 3.1. Layout of coal exploitation performed in years 2003–2005 at area of A4 highway

Fig. 3.1. Schemat dokonanej eksploatacji w latach 2003–2005 w rejonie autostrady A4

4. Influences of exploitation on the ground surface

Influences of mining exploitations conducted from 1947 to 2003 are defined theoretically. Surface subsidence along the highway axis from km 327+100 to 328+000 (between faults III and IV) was presented in the fig. 4.1. Within the parking place a "subsidence crest" occurred where subsidence came to about 1.5 m, to the west and east subsidence increased to

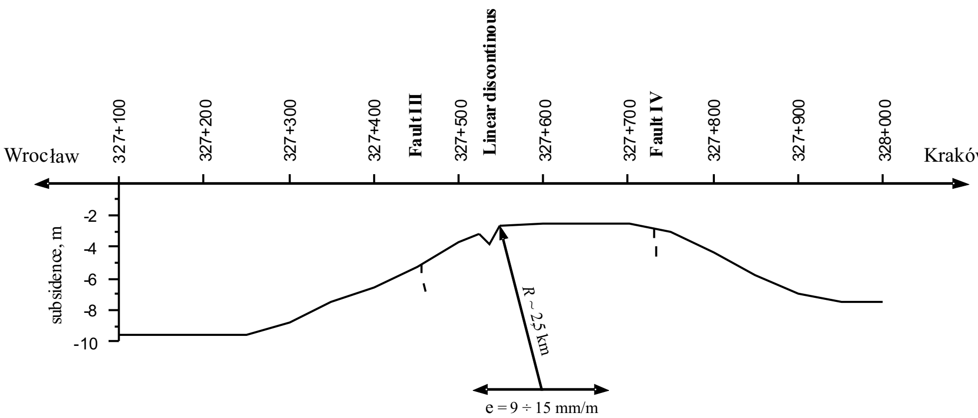

Fig. 4.1. Subsidence of surface in highway A4 axis before commencement of construction works at area of faults III and IV, due to performed exploitation and estimated horizontal deformation ε

Fig. 4.1. Obniżenia powierzchni w osi autostrady A4, w rejonie strefy uskoków III i IV przed rozpoczęciem budowy autostrady, spowodowane dokonaną eksploatacją górniczą i szacowane odkształcenie poziome ε

about 10 meters. Radius of convex flexure of surface numerically estimated from subsidence amounted to 2.5 meters. In the zone between faults III I IV there have occurred horizontal tensile deformations that were summing up. Within the area of discontinuity they amounted to +9.0 mm/m to +15.0 mm/m.

Highway subsidence from 03.2003 to 12.08.2005 measured within conducted geodetic monitoring were presented in the fig. 4.2.

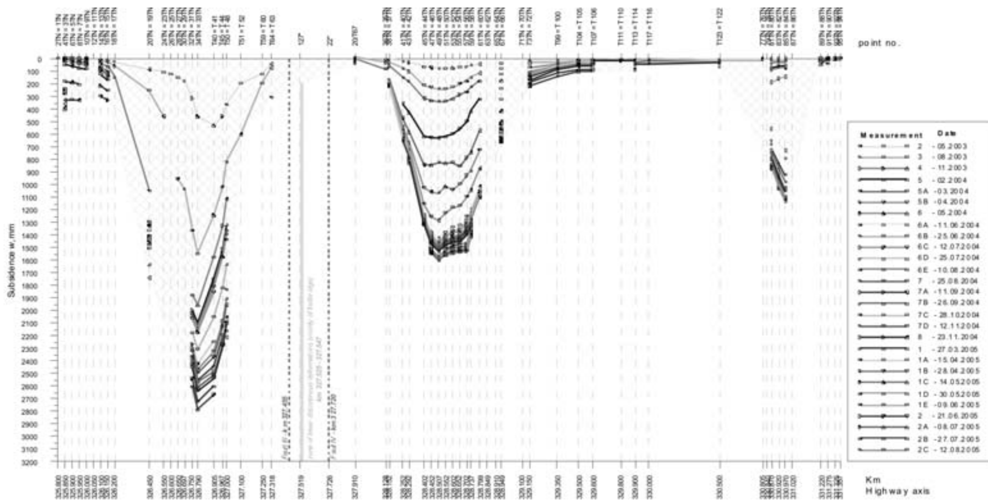

Fig. 4.2. Measured subsidence along the longitudinal axis of A4 highway in period from 03.2003 to 12.08.2005

Fig. 4.2. Obniżenia pomierzone wzdłuż osi budowanej autostrady A4 od 03.2003 do 12.08.2005 r.

Considering the location of parking place, most of measurement points within the zone of the highway were destroyed. Despite their lacks subsidence defined from March 2003 to August 2005 in the area of discontinuity amounted to about 0.2 m. To the west and north of the discontinuity subsidence amounted respectively in km 326+680 to 2.8 m and km 328+560 to 1.7 m. Radius of flexure estimated from subsidence amounts to about 10 km.

Later conducted measurements of roadways of A4 subsidence, from 30 May to 30 August 2005, showed its slight increase amounting to 34–37 mm. Vectors of measured horizontal displacements of points on the A4 roadways from the area of discontinuity amounted to 26 to 57 mm and were directed to the north and northwest, in the direction of exploitation conducted in the seams 415/1 and 504 (compare fig. 3.1). Computationally estimated values of horizontal deformations being results of exploitation conducted from the half of 2002 to August 2005 amounted to about +1.8 mm/m. Assuming a proportionality between values of measured subsidence of the highway axis in the period of its construction (0.2 m) to the values measured after the highway completion (0.07 m), estimated values of horizontal deformations of the highway structure amounted to +0.6 mm/m.

5. Geophysical research during the highway construction

Geophysical research is one of manners being used to characterize the disturbance zones of layers of geological and mining origin (Kotyrba 2002, 2006; Kotyrba, Kłosek 2000; Pilecki 2003, 2008; Pilecki, Kotyrba 2007). First geophysical measurements in the parking area (series I-a) within faults III and IV were conducted under circumstances of great progress of earthworks on the A-4 route (October 2003). Only the axis of planned highway was indicated in the field which the localization of geophysical profiles was referred to. This section of the highway is in the phase of excavation which is a part of extensive morphologic elevation slit formed with carboniferous rocks (fig. 5). Geophysical measurements were conducted during the period of abundant rain. Thus near-surface ground layers were watered. It caused that clays occurring in this area became plastic and locally liquefied. In the southern part of the designed highway a 10 meters high pile of building soil was raised. Surface conditions predestinated research of this area with electro-resistance method.

Carboniferous formations exposed in the excavation with regard to almost zero thickness of quaternary sediments in the highway bed. It results from geological drillings that their roof is built by clayey loam waste.

Geophysical measurements with the method of double-level electro-resistance profiling were conducted for three profiles with P1, P2 and P3 symbols, situated in parallel with the highway axis in km 327+390 – 327+510 (fig. 5.1 and 5.2). In measurements Schlumberger symmetric array with A10M5N10B and A30M5N30B spacing was applied which ensured rock mass penetration on estimated depths of respectively 5 and 13 m under the ground

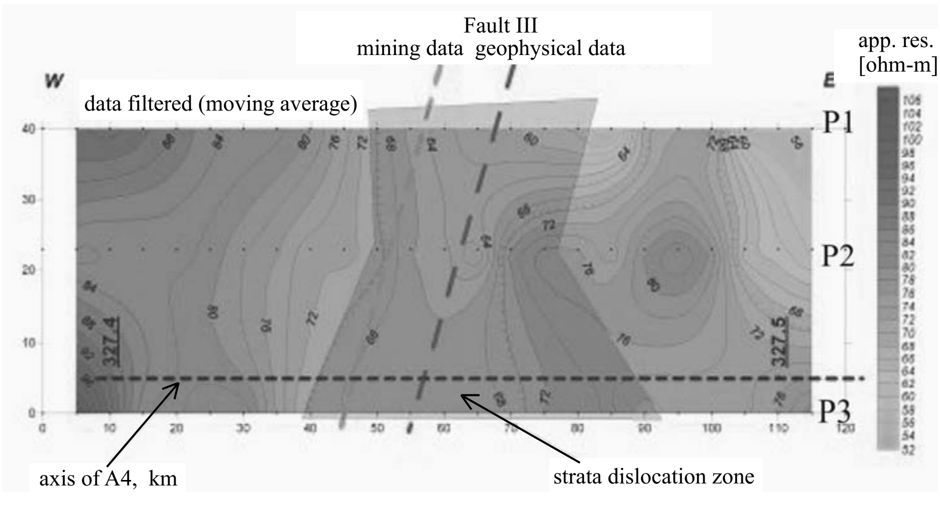

Fig. 5.1. Iso-ohm contours registered in subsurface soil during I[st] series of resistivity measurements at segment in km 327.390–327.510 (P1, P2,P3 – measurement profiles)

Fig. 5.1. Izoomy poziome zarejestrowane w gruntach przypowierzchniowych w I serii pomiarów na odcinku w km 327.390–327.510 (P1, P2,P3 – profile pomiarowe)

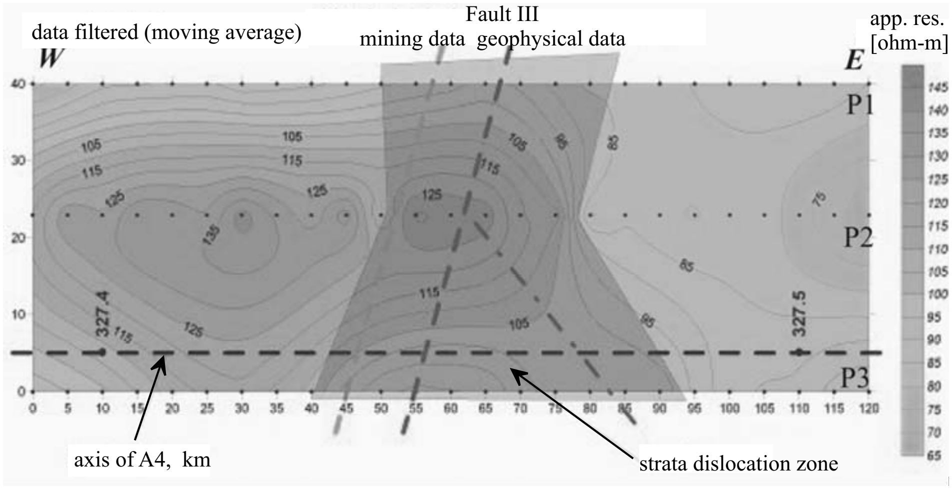

Fig. 5.2. Iso-ohm contours registered in bedrock during Ist series of resistivity measurements at segment from km 327.390 to km 327.510 (P1,P2,P3 – measurement profiles)

Fig. 5.2. Izoomy poziome zarejestrowane w utworach skalnego podłoża w I serii pomiarów na odcinku w km 327.390–327.510 (P1, P2,P3 – profile pomiarowe)

surface. Distances between points on the profiles were equal to 5 meters. Measurement data were strongly diverse (high changeability gradients of apparent resistivity between each point) in the range of the values from 60 to 140 ohm for the array with deeper reach and from 50 to 110 ohm for the array with shallower one. This diversity results from degree of rocks weathering changeability in each region of investigated area. Higher values of apparent resistivity are characteristic for weakly weathered rocks. Thus measurement data were filtrated.

Research results such as horizontal layout of specific resistivity values of bedrocks (after their filtration) at each depth were presented in the fig. 5.1 and 5.2. Their analysis shows that array with shallower reach penetrated mainly a layer of weathered loams. It results from relatively lower level of electric resistivity value than registered with a array with deeper reach.

In iso-ohm layout for this array, dislocation zone of a fault is stated as low-resistance anomaly. In the interpretation it was assumed that it is caused by water drainage from the part of waste rock material to fissures within deeper bedrock. The layout of apparent resistance values of rocks from deeper layers of the bed is presented in the fig. 5.2. On the image of iso-ohms layout presented in the above mentioned figure, the bed of investigated area is divided into a higher-resistance part with values amounting to 100 and more ohm (in the western part) and lower-resistance part (in the eastern part) with values amounting to 80 and less ohm. Iso-ohm image at this depth is disturbed additionally by presence of outcrops of lithologically different carboniferous formations.

An outcrop of sandstone layer (with resistance value of 130 ohm) can be found in the central part of the investigated area, from the west. In the southern part of the investigated area a strip of increased resistance values turns to the east. Thus the course of dislocation zone was widened in the above mentioned direction in relation to the one defined on the basis of analysis of data registered with an array with shallower reach. It seems to be possible that such shape of dislocation zone results from the presence of a single fissure in the ground that goes away from the main throw surface in the southeast direction. The localization of dislocation zone was defined on the basis of complex analysis of geological, mining and geophysical data. It was assumed eventually that the main fault surface crosses an axis of the highway in km 327+446 while a lateral fissure in km 327+465. It resulted from the data analysis that locally within the area of fault surface gapping fissures can be found. In the depth zone of 0–5 m under the ground surface they are filled with loam soil with sandy and dusty particles. It resulted from the analysis of geophysical data that in their deeper part the fissures were filled with ground material.

6. Geophysical research after the highway completion

Damages of roadway structure (discontinuities) are the reasons of geophysical research continuation in the area of fault III (measurement series II I III) in the year 2005. They were localized about 85 meters to the east from indicated line of fault III. Research covered the section of about 200 meters, including the area of I series measurements as well as the area of observed roadway damages in the vicinity of a footbridge. Research localization is presented in the fig. 6.1.

Fig. 6.1. Location of geophysical measurements in the year 2005 on satellite image background
1 – measurement profiles, 2 – faults, 3 – discontinuity in asphalt roadways

Fig. 6.1. Lokalizacja badań geofizycznych w roku 2005 na zdjęciu satelitarnym
1 – profile pomiarowe, 2 – uskoki, 3 – nieciągłość (próg) w jezdniach A4

Research was conducted by the method of multi-level electro-resistance profiling (WPE) as well as georadar pictures (GPR). A set of data from electro-resistance measurements was strongly diverse both from the point of resistance value and spatial location of characteristic anomalous points that could be attributed to the elements of the bed discontinuity.

Due to the above mentioned reasons a set of data including differences of resistance value in each point of II and III measurement series was created. The above mentioned differences were expressed as per cents of series II resistance value and subsequently they were set together in form of horizontal iso-ohm maps (resistance horizontal layouts). The results of such elaboration and data presentation were shown in the fig. 14. In the applied colour scale darker tones indicate areas of resistance value decrease. Bright tones indicate areas of resistance value increase. On both intersections isoline with its value of +2% was identified. Analysing differential images with respect to quantity (amplitude and resistance changes symbol) presented in the fig. 6.2, significantly greater changes of resistance value can be observed in deeper parts of a rock mass than in shallower ones. It confirms a conclusion of the I series measurements interpretation that in deeper parts of bed there can be found gaping fissures unstructured with ground material originated from overburden, what results in relatively greater resistance of a rock mass.

In the horizontal image of a layout of near-surface layer resistivity changes (upper part of fig. 6.2) both location of the fault III and threshold reveal a correlation with route and shape of isolines of percentage changes. However only the line of the fault is a border between areas of various symbol of resistance values changes (to the west- resistance value decreases, to the east- resistance value increases). The zone of discontinuity- threshold exposes on this image as a strip of irregular shape where resistance value increases for more than 4%.

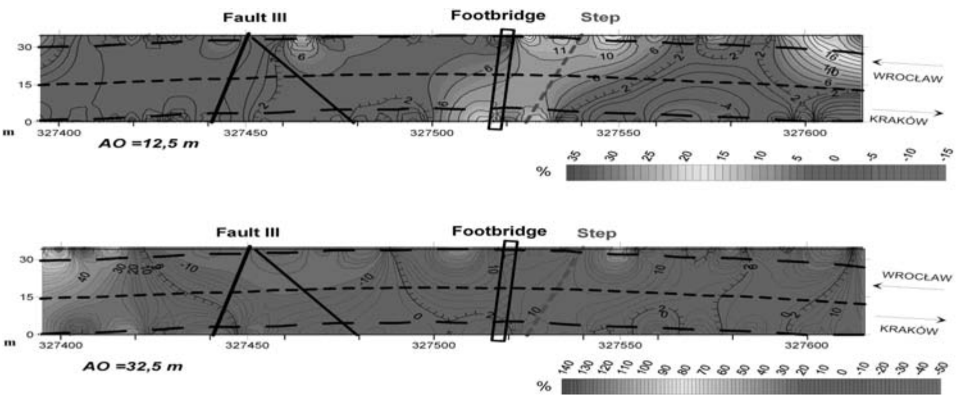

Fig. 6.2. Maps of soil and rock apparent resistivity changes (expressed as a percentage of initial values) between III and II measurement series (upper image – subsurface soil, bottom image – bedrock)

Fig. 6.2. Mapy zmian pozornego elektrycznego oporu właściwego (wyrażonych w procentach) pomiędzy pomiarami serii III i II (płytsze podłoże – górna część, głębsze podłoże – dolna część)

The width of this strip is larger in its north part (roadway towards Wrocław) than in the south one (roadway towards Kraków). Assuming that dislocation zone it is an area where resistance value increased, then in the north part it is 100 meters long and in the south part about 80 meters.

A detailed image of road body structure and its direct bed was obtained as a result of geophysical research with georadar method (GPR). In the research a monostatic broadcasting-receiving antenna with its frequency of 500 MHz was applied. Depth radar sections registered on roadsides of the north and south roadways were presented in the fig. 6.3 and 6.4. Surface reverberation (from the asphalt) was filtered numerically on both registrations. Both

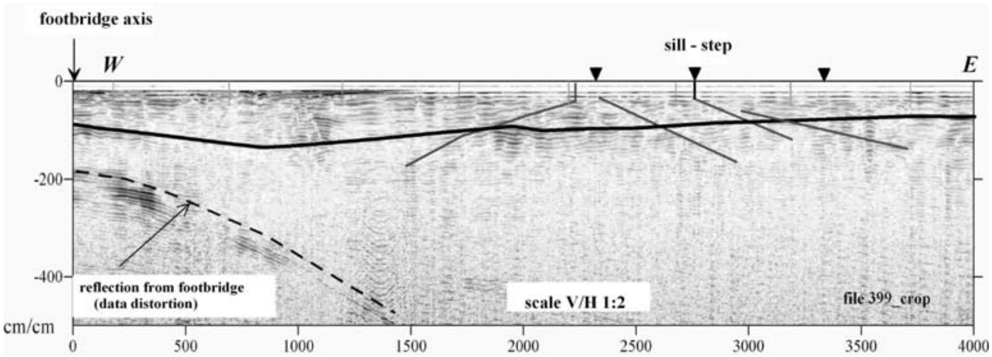

Fig. 6.3. Substrate discontinuities in the northern shoulder of A4 roadway (direction Wrocław) at area of sill in GPR image (depth section)

Fig. 6.3. Nieciągłości w podłożu północnego pobocza jezdni A4 (kierunek Wrocław) w rejonie progu w obrazie głębokościowej sekcji radarowej

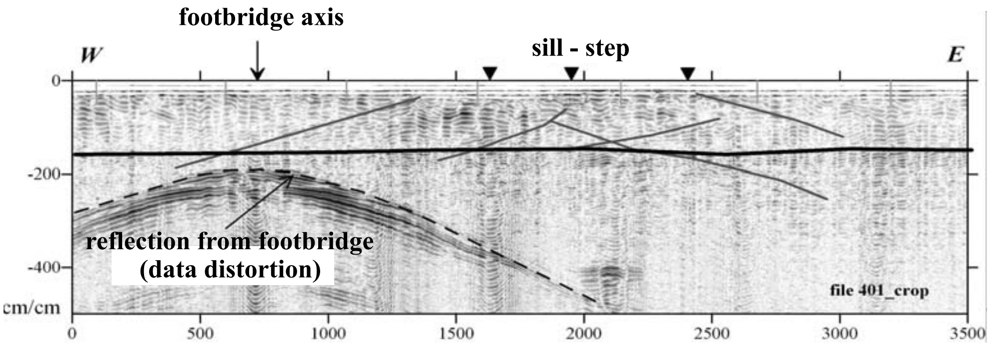

Fig. 6.4. Substrate discontinuities in the southern shoulder of A4 roadway (direction Katowice) at area of sill in GPR image (depth section)

Fig. 6.4. Nieciągłości w podłożu południowego pobocza jezdni A4 (kierunek Katowice) w rejonie progu w obrazie głębokościowej sekcji radarowej

registrations are disturbed by strong surface reverberation from the footbridge structure. It can be distinguished only one quasi-horizontal reflective horizon on the sections, which probably corresponds with a border between road foundation and genuine bed (at the depth from 1 to 1.8 m). In the area of a threshold a few reflective horizons with diagonal course can be distinguished (marked with red colour). They cross road foundation layer and reach a layer of genuine bed.

The above mentioned horizons have opposing dip angles. Inclinations of these horizons are not large taking into consideration superiority of vertical scale on the sections (2:1). Dip angles vary within the range from 12–20°. Such small angles of reflective horizon dips let to believe that their origin should be searched rather in a phenomenon of ground chamfer building the bed of the road than in cracks of tectonic origin. The above mentioned hypothesis is also supported by the fact that there are few discontinuity surfaces and they have opposing dips. The location of the zone where horizons may be observed correlates well with results of electro-resistance research. The highest temporal changes of the bed resistance were registered within a near-surface layer with its thickness comparable with the layer penetrated with radar.

A presented interpretation of georadar research (GPR) results is not so unequivocal as electro-resistance research, geodetic monitoring results of the highway and counted surface deformations. However from presented analyses it results as follows:

- before the highway construction its bed was significantly deformed, it met especially horizontal deformations with tensile character as well as convex flexures being of limit values of IV and V category of mining country,
- during the highway construction its bed yielded horizontal deformations of the value of I and II category of mining country,
- originated discontinuity is connected with deformations of tensile character that occurred within the area of the highest horizontal tensions about 85 meters to the east from an outcrop of the fault III, not on the outcrop!

Summary

Construction of new transport routes within the areas of hard coal deposits in the USCB significantly restricts the possibility of their usage. Prediction and control of post-exploitative ground deformations where a rock massif appears on the surface is very difficult as discontinuous deformations of overburden rock layers are predominant. There are no effective and cheap protections against such deformations.

The analysis of research results from the area of Halemba-Wirek parking area as well as history of conducted exploitation and accompanying surface deformations permitted to make the following characteristic of processes taking place in a rock mass:

- Formation of the zone of horizontal tension in a rock mass and with convex flexure on the surface of subsidence basin caused discontinuities (fissures, stage) in a carboniferous rock massif with diagonal course through Halemba-Wirek parking place just in the year 2003.
- Bed deformations occurring during the highway construction (years 2003–2004), especially horizontal deformations and flexures with the same character as previous

ones, caused an activation of discontinuity existing in a rock mass, and in the year 2005 it resulted in an origin of discontinuities on roadways.

— In the second half of the year 2008 on the site of discontinuity repaired in the year 2006, a highway body is still being deformed- a discontinuity activates despite the lack of mining exploitation.

A presented example of discontinuity formation, its genesis and activation is an important experience in the scope of such discontinuities recognition, the possibility of their predicting and effectiveness of road infrastructure protection.

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LINEAR DISCONTINUOUS DEFORMATION OF A4 HIGHWAY WITHIN MINING AREA "HALEMBA"

K e y w o r d s

Hard coal mining, highway deformation, geodetic and geophysical measurements

Abstract

Construction of new transport routes within the areas of hard coal seams exploitation in the USCB causes various difficulties for mines and for the quality of roads. One of them is maintenance of permissible dimension of surface deformations and situated buildings. Less than one year after construction works of A4 highway had been completed discontinuous deformations such as fissures and stages occurred on roadways and adjacent area of parking place (MOP Halemba-Wirek) within mining area "Halemba". The above mentioned resulted in a necessity of pavement and substructure replacement within the damaged part of the highway. Geodynamic processes that caused the above mentioned deformations still last and lead to the next highway reparations. In the article there was presented a complex analysis of geological and mining conditioning of deformations as well as collected observation and measurement data. A set of data includes the results of geodetic and geophysical measurements executed during the highway construction period as well as after its completion.

LINIOWA DEFORMACJA NIECIĄGŁA AUTOSTRADY A4 NA OBSZARZE GÓRNICZYM „HALEMBA"

Słowa kluczowe

Górnictwo węgla kamiennego, deformacja autostrady, pomiary geodezyjne i geofizyczne

Streszczenie

Budowa nowych szlaków transportowych na terenach eksploatacji złóż węgla kamiennego w GZW stwarza różnego rodzaju problemy dla kopalń i utrzymania jakości dróg. Jednym z nich jest zachowanie dopuszczalnych wielkości deformacji powierzchni i usytuowanych na niej obiektów budowlanych. W niecały rok po zbudowaniu autostrady A4 na terenie obszaru górniczego „Halemba" na jezdniach oraz w przyległym do nich terenie miejsc obsługi podróżnych (MOP Halemba-Wirek) wystąpiły deformacje nieciągłe w postaci szczelin i stopni. W efekcie konieczna była wymiana nawierzchni i podbudowy na uszkodzonym odcinku autostrady. Procesy geodynamiczne, które wywołały deformację trwają nadal prowadząc do kolejnego remontu drogi. W pracy przedstawiono kompleksową analizę uwarunkowań geologiczno-górniczych deformacji oraz zgromadzonych danych obserwacyjnych i pomiarowych. Zbiór danych obejmuje wyniki pomiarów geodezyjnych i geofizycznych wykonywanych w okresie budowy autostrady oraz po jej zakończeniu.