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A4 motorway operation in the area of linear discontinuous surface deformations

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ABSTRACT: The A4 motorway is a very important element of transport network in Poland linking East with West. In a section a few dozen kilometers it passes through the Upper-Silesian Industrial Conurbation, where mining and post-mining areas exist. The A4 motorway section passing through the area of linear discontinuous surface deformations (LDSD) should be considered especially crucial. In this area, immediately after the construction of pavement (2003), damage emerged on the right-of-way surface in the form of steps and single cracks nearly perpendicular to the road axis. During more than decade of motorway use in this area the damage was reproducing despite performed repairs. A thorough reconstruction of the pavement and subgrade improvement started in 2015 provides an opportunity to sum up the carried out tests, analyses, and previously presented theses. An extremely significant advantage of the started construction works is a possibility to verify the actual condition of layers building the pavement and its subgrade and to compare it with previously made theses and expressed opinions. The observations and conclusions presented in the paper are based inter alia on results of drilling through the pavement and subgrade, geophysical tests, analyses of geological-mining situation, land surveying, measurements of pavement deflection by FWD and visual inspections.

1 INTRODUCTION

The section of A4 motorway passing through the area of Upper Silesia in the southern part of Poland (Fig. 3) is an example of difficult coexistence of the deep hard coal mining and the transport infrastructure operation. The road pavement durability is equally significant parameter determining its technical condition, depending on the stiffness of pavement structural layers and of the subsoil. Mining deformations have always a negative impact on the pavement. In the case of continuous deformations, described by a subsidence trough, high-speed roads may operate retaining permissible speeds, but subject to some restrictions in the mining operations, hereinafter referred to as the mining preventing actions. Also on the construction side it is required to apply construction prevention activities and of carrying out the roadway monitoring.

Significantly more complicated situation occurs in the case of discontinuous deformations. In such cases the ground surface continuity is broken and sudden changes in the ground profile originate, including the roadway (Pic. 1). Deformations are frequently accompanied by discontinuities of surface nature (Pic. 4). The case described in the paper is related to the motorway, on which linear discontinuous deformations have been appearing since the beginning of its use and which originated from the past mining operations and from impacts of the current mining. For the analysed motorway section the consecutive events have been presented chronologically, related to: the historical and current mining operations, the phase of construction, deformation development on the surface, the pavement repair, and tests.

Pic. 2-1. A linear-type discontinuous surface deformation (Grygierek 2010)

2 MINING OPERATIONS BEFORE THE MOTORWAY CONSTRUCTION

The past mining operations in the analysed area were carried out from 1947 in 15 seams, most frequently with caving. The mining depth ranged from 200 m to 900 m. The mining was concentrated west and east of existing there fault zones III and IV. The result of mining carried out this way was a large difference in subsidence, because in the section connecting the fault zones the subsidences were approx. 1.5 m and west and east of the fault zones they reached 10 m (Fig. 1). Papers (Kotyrba at al 2009) (Kotyrba at al 2015) (Kotyrba A. 2006) present a detailed analysis of mining conditions.

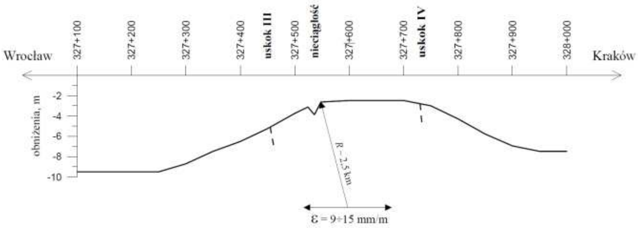

Figure 2-1. Surface subsidence in motorway axis, in the area of fault III and IV zone before the construction start, caused by the past mining operations (Kotyrba at al 2009). uskok = fault; obniżenia = subsidences

3. MOTORWAY CONSTRUCTION PERIOD

3.1 The Roadway Description And The Pavement Structure

The analysed area covers a strip of land corresponding to A4 motorway section from km 327+400 to km 328+400. The construction was carried out in the period 2002-2005. The Service Areas (MOPs), on the southern and northern side of the road, are characteristic facilities in this section. This section goes on the ground on the northern side and in an excavation on the southern side. The northern part of MOP is built of Quaternary sediments, which cover Carboniferous in layers from 0 to around 3 m thick. There are mainly clays.

Firm silty clays and sandy clays should be distinguished among them, with admixture of gravels and sand interlayers. The clays condition is specified as very stiff or stiff. In the southern part of MOP there are Carboniferous strata, which are covered by embankment layers 0 to 3 m thick. It should be stated that the geological structure of the whole area is inhomogeneous, affected by the course of Carboniferous formation roof. As mentioned earlier, in the MOP area there are two faults marked as III and IV, with throws of 20 m and 10 m, respectively.

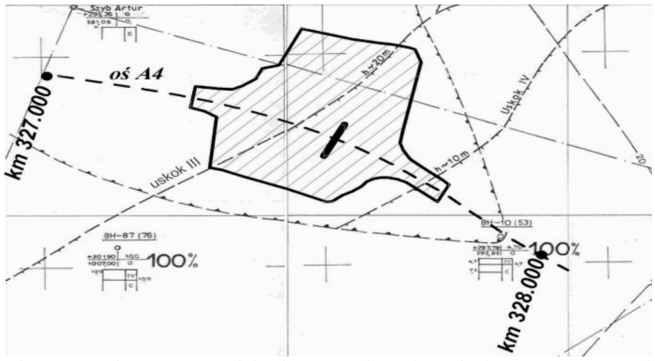

Fig. 3-2. The course of fault III and IV in relation to MOP and A4 motorway (Kotyrba & Kowalski 2009)

A detailed description of the geological structure may be found in reports prepared under A. Kotyrba and A. Kowalski direction, research staff members of the Central Mining Institute in Katowice (Kotyrba at al 2009) (Kotyrba at al 2015) (Kotyrba 2006). The cross-section comprises two roadways (2x14.75m) with three lanes (3x3.75m) and an emergency lane (3.00m) each way with service areas on both sides.
The pavement after commissioning (2003) featured the following arrangement of structural layers:

- 5 cm, wearing course SMA 0/12.8,
- 10cm, binding course BAWMS 0/25,
- 10cm, base course BAWMS 0/31.5,
- 22cm, aggregate base course 0/31.5,
- Tensar SS-40 stabilizing monolithic geogrid,
- 20cm, engineering course 0/63,
- 20cm, frost protection layer 0/63,
- Geotextile layer and foil layer,
- Approx. 40 cm, stabilised subgrade layer (slag + large aggregate).

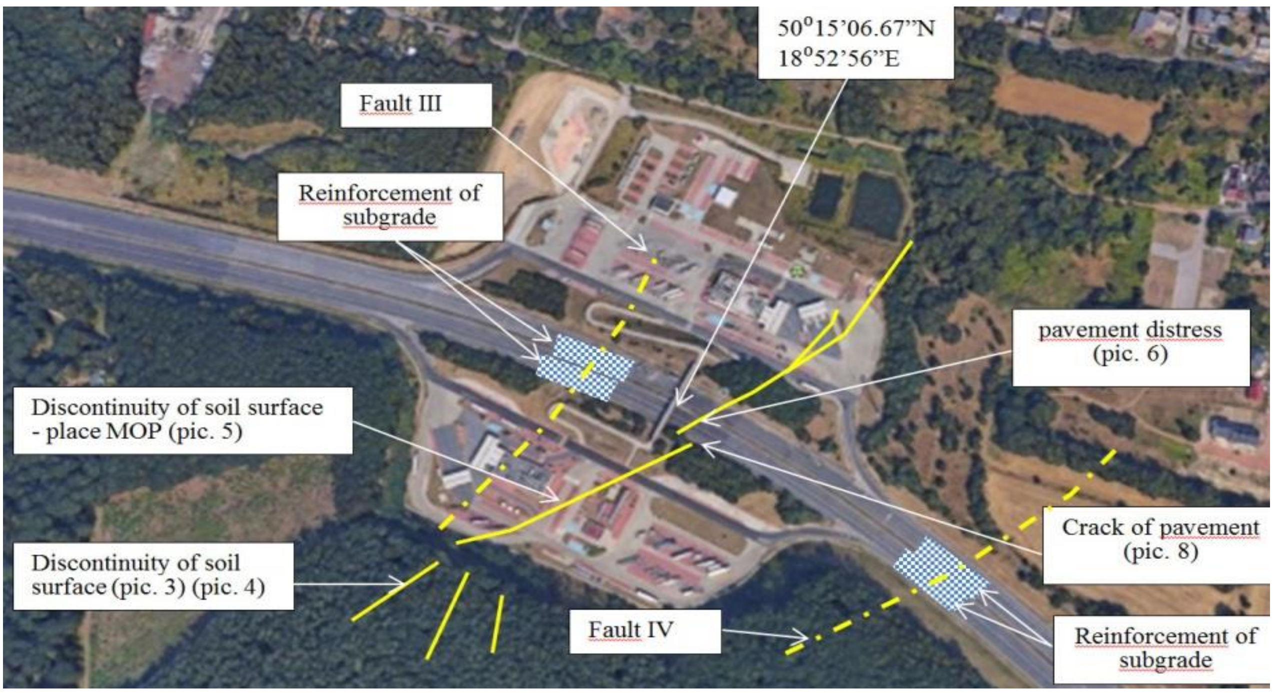

Figure 4-3. Location of events in the motorway right-of-way and in the adjacent area (Google Earth)

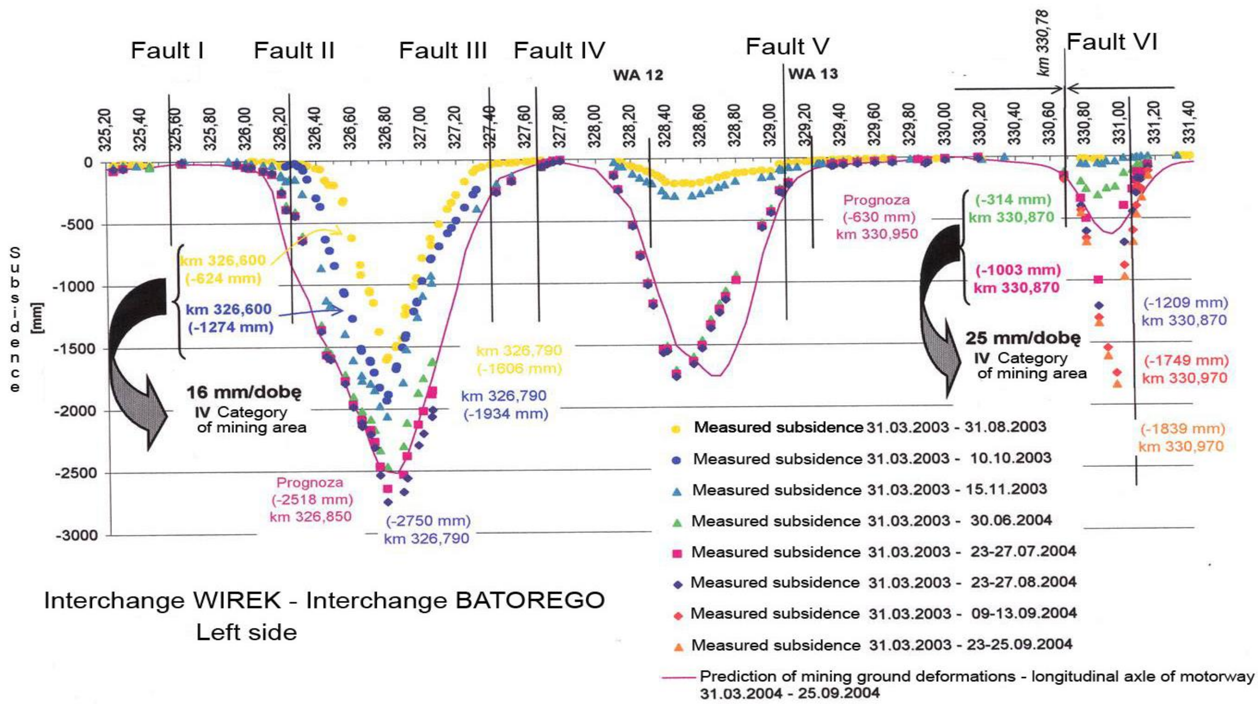

Fig. 6-3. Subsidence of A4 motorway right-of-way measured in the period Mar 2003 - Nov 2004 (Chlipalski at al 2010)

In fault zones (fault III and IV) in a section approx. 100 m long an additional reinforcement was applied in the form of a geomattress 50 cm thick, with inserts of uniaxial polypropylene geogrids of high short-term tensile strength at the bottom and at the top. The geomattress was built-in on a layer of so-called "sand pad" and was situated around 2 m deep from the road formation line.

3.2. Surveying Monitoring

A network of surveying monitoring points, mainly along the boundary of the motorway right-of-way, was designed and constructed due to the forecast impacts of mining operations. The idea of surveying monitoring consisted in cyclically made surveying measurements, based on which the forecast deformations were compared with the actual, i.e. measured, ones.

Conclusions from the comparative analysis were crucial, because they determined the further progress of works and the introduction of design changes, which were forced due to the adaptation of the motorway parameters (the formation line) to the required values.

3.3. The Mining Operations Impact On The Ground Surface. Measurement Data Analysis

During the carried out construction works the intensity of ground surface mining deformations, including the motorway right-of-way, was extremely high, nearly along the entire contract section (6 km). It is worth noticing that the greatest subsidence exceeded the value of 2.5 m (between 2002 and 2004).

Pic. 4-2. Survey of the next phase of discontinuous deformations development - 16 October 2003 (Strycharz B. at al 2005)

It is a characteristic fact that the analysed motorway section (from km 327.400 to 327.800) was situated on a ridge of two subsidence troughs, which originated on both sides of the fault zone (Fig. 3) and certainly by their reach covered this zone, resulting in subsidence from 17 mm to 27 mm. However, the most significant fact is the same nature of deformations distribution on the surface as that originating from previous mining operations (Fig. 1), i.e. from the period 1947 - 2002

Permanently superimposing tensions in the rock mass resulted in the origination in the fault zone of so-called linear discontinuous surface deformations, which first symptoms were visible as early as during the motorway construction in the forest area adjacent to the motorway right-of-way.

Till the construction works completion (2004), the discontinuous deformations emerged only in the ground strip adjacent to the motorway right side. No discontinuities were recorded during the construction period, in the right lane and in the service areas.

4. MOTORWAY OPERATION AFTER CONSTRUCTION

4.1. Motorway Pavement Damage In 2005

The next discontinuities in the analysed area were recorded in May 2005, that is less than a year from the motorway commissioning. Deformations occurred on both roadways (Pic. 3) and in the area immediately adjacent to the roadway, including the area of MOP still under constructio.

Pic. 6-3. Pavement damage observed in May 2005 (Kowalski 2015).

The course of those deformations did not coincide with the course of earlier faults III and IV. Unfortunately, deformations occurred on the motorway section not protected against such mining impacts. On the roadways the deformations caused unevenness in the form of corrugations, accompanied by cracks of significant opening (fissures). The cracks were going in the NE direction. Corrugations that occurred on roadways were cold milled and the cracks sealed; afterwards a repair design preparation started. An unfavourable geological structure of the rock mass, the existence of faults III and IV zone in the area where no mining operations were carried out, the Carboniferous strata outcrops on the surface, the lack of younger strata overburden, as well as the past mining before the motorway construction west and east of the fault zone, which resulted in the origination of a zone with accumulations of horizontal tensile deformations, were considered causes of deformations observed in the motorway right-of-way at that time.

The mining operations carried out during the motorway construction resulted in increments of horizontal deformations on the ground surface of around 1.8mm/m, including 0.6 mm/m after the motorway construction. Also we should not forget the total values of deformations from the period before the motorway construction (1947 – 2003), when the deformations were estimated at +9 mm/m to +21.0 mm/m

The geophysical - electric resistance studies performed at that time allowed finding the existence of open cracks not filled with the soil at deeper parts, which confirmed a destructive nature of the carried out mining operations before the motorway construction start. Apart from electric resistance tests also a georadar measurement was applied, due to which an image of the road body and its immediate subsoil was obtained.

Because of the originated deformations, the pavement was repaired in a section approx. 20 m long - removing the pavement layers to the floor of broken aggregate subgrade 0/31.5 (bottom subgrade layer). Finally, in 2007 the following arrangement of layers was executed:

- 5 cm, wearing course SMA 0/12.8,
- 10cm, binding course BAWMS 0/25,
- 10cm, base course BAWMS 0/31.5,
- 22cm, aggregate base course 0/31.5

Flat biaxial geomesh of welded strips 40/40 (PP)

Taking into consideration the performed reinforcement it should be noted that it features a minimum reach (intervention) in the pavement, because to a depth of 47 cm, including 22 cm below the mineral-asphalt pavement.

4.2. Motorway Pavement Damage In The Years 2007 - 2015

The pavement repair described in section 4.1 was implemented in 2007. Shortly after in the area of discontinuity existing between faults III and IV the discontinuous deformations opened again. If for the first time (2004) the deformations occurred in a strip of around 20 m passing skew to the road axis, i.e. at an angle of approx. 66º (SW-NE), then in the next years the deformations concentrated in a very narrow trail, i.e. in the form of a step passing in the central part of 20 m strip and with a course consistent with the direction of previous damage.

The cohesion of MMA (mix asphalt) layers was seldom disturbed due to a relatively slow deformation build-up. A small deformation increase with time and the asphalt mix flexibility (viscous properties) in the period of higher temperatures existence allowed the asphalt mix to adapt to the deforming subsoil on a current basis (Pic. 4).

Pic. 7-4. Deformation of the northern roadway of A4 motorway - 5 August 2010 (Grygierek at al. 2015)

In the analysed period the reproducing step caused restrictions in the traffic due to a limited speed and unevenness. This situation forced to make the next repairs, which took place in 2011 and in 2014. Both repairs consisted only in the profiling of the longitudinal pavement profile, i.e. in cold milling and building in a levelling and the wearing course.

The durability of such treatments was only temporary, because after a short time the step was again felt by the drivers. It is worth adding that based on the collected surveying measurements data the subsidence in the fault zone in the period 2006 - 2012 amounted to approx. 75 mm, and the mining was carried out at a distance of more than 350 m (Kotyrba, Kowalski 2015)

5. 2015 DEMOLITION WORKS

As a result of frequently occurring difficulties a repair design was developed in 2012, which was implemented in the second part of 2015.

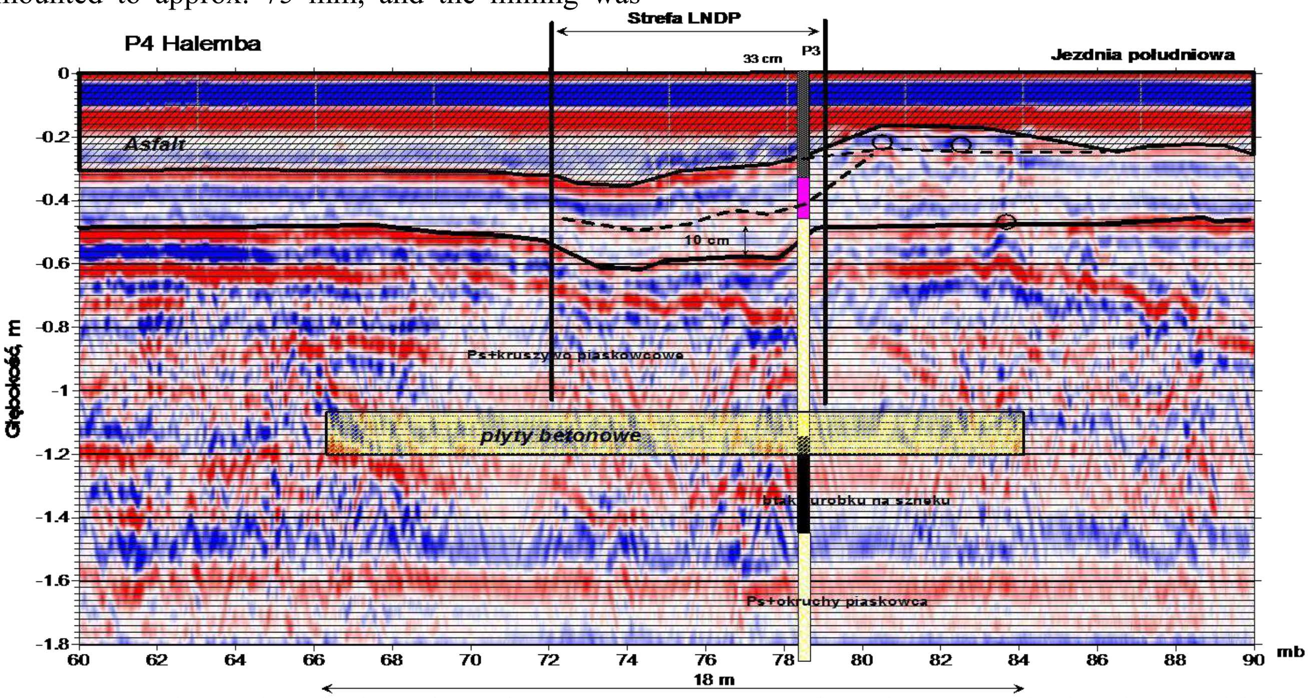

Fig. 7-4. Deformations of the embankment layers down to approx. 1.0 m. (Kotyrba at al 2015) (Grygierek at al 2015) Głębokość = Depth; Strefa = Zone; Jezdnia południowa = Southern roadway; kruszywo piaskowcowe = sandstone aggregate; płyty betonowe = concreto slabs; okruchy piaskowca = sandstone chips.

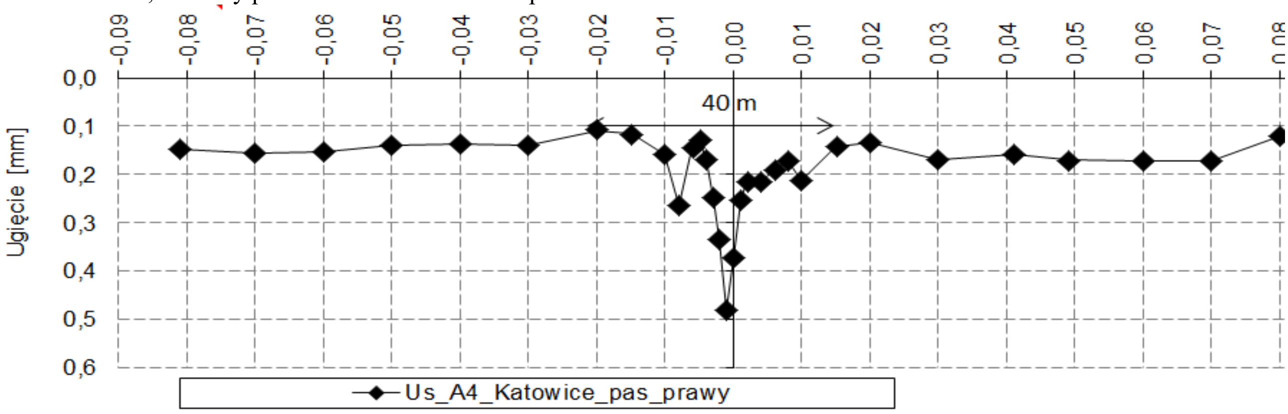

Fig. 8-5. Results of pavement deflections measured by an FWD (Falling Weight Deflecotmeter) (Grygierek M. & Kawalec J. & Kwiecień S. & Mencfel R. 2015). pas_prawy = right-hand_lane.

The design work included the performance of geophysical surveys and of geological-engineering boreholes, based on which the scope of construction works was planned.

The studies carried out at that time by the design entity indicated a possibility of voids existence in the rock mass, hence the treatment works (voids filling) were designed. The studies repeated by the works Contractor before taking over the right-of-way (geophysics, boreholes, probing) as well as the construction works themselves rejected the existence of any voids, and also the existence of significant cracks. Even more, based on georadar surveys it was found that the biggest anomalies, including profile deformations, existed in the embankment layers, i.e. situated at a depth of approx. 1.20 m between the native subsoil and the mineral-asphalt pavement.

This observation was one of arguments, based on which an alternative solution was suggested, which *inter alia* consisted building-in a reinforced concrete - pin jointed slab at a depth, at which the deformations disappear (Fig. 4). Attention was also paid to the subsidence, on the radarogramme, in the area of actual fault III outcrop. In fault III area, during the surveying work, a mild pavement deformation was found, visible in particular on the edge line. The work preceding the construction works included the performance of pavement deflection measurements using an FWD instrument, to evaluate the impact of discontinuities on the pavement deflections distribution, and thus on the stiffness of the layer system building the pavement structure (Fig. 5). The test force of 90 kN was applied during the test for a better penetration of the pavement and subsoil layers. The obtained deflections distribution reflects well the results of georadar surveys. Zones of similar profile deformation length were obtained on both graphs - georadar and deflection increase (FWD). It is worth noting that beyond the discontinuities zone (approx. 30-40 m), the pavement featured very small deflections, i.e. below 0.20 mm at the MMA layers temperature of 20°C and the test force of 90 kN.

Finally, the pavement subsoil structure consisting of a package of a few goegrid geomattresses featuring a very high long-term strength, a slip layer and other aggregate layers was made as a protection, in total 2.0 m thick. The pavement structure was build on the subsoil prepared this way.

6 SUMMARY

Selected events related to the motorway operation in a very difficult area, situated within the reach of deep mining operations, have been presented. The motorway was constructed in extremely difficult conditions, resulting from the necessity of construction works and mining operations - and related intense ground deformations - coexistence. The past mining in the area of the analysed section, carried out taking into account faults III and IV existing at a small distance, resulted in high tensions in the rock mass, which in effect led to the initiation of a discontinuous deformation phenomenon between these faults, in addition in the place, where no protections in the subsoil were applied. The next years of the motorway operation witnessed the next events, related to the origination and then the reproduction of discontinuous deformations in the same location. Studies carried out, in particular before this section reconstruction start, allowed to determine the length of this section weakening zone to approx. 30 m - 40 m. Also the geophysical surveys and the pavement deflection measurements by an FWD instrument turned out to be helpful to determine this scope. The adopted solution, based on a system of geomattresses, using among others a geogrid of high long-term strength, will allow to verify the implemented reinforcement concept. However, it is necessary to add, that this section will be situated beyond the area of main impacts.

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