Damage to Road Pavements in the Area of Linear Discontinuous Deformations on the Surface Caused by Deep Mining

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Abstract. Deep mining extraction causes deformations on the surface, which have a negative impact on road pavements located in the area of their influence. Discontinuous deformations are a special case of surface mining deformations, which arise in the area of impact of deep mining extraction where longwalls in subsequent seams are overlapped. These deformations take the form of surface thresholds, which are often accompanied by the discontinuity of the subsurface soil layer. In the article, this type of damage which occurs on the roadway, in particular on the road pavement, was characterized. The damage leads to the deterioration of longitudinal evenness of pavement, which causes discomfort during driving, and may even pose a threat to road traffic safety.

1. Introduction
Underground mining extraction causes deformations on the surface, which take the form of the so-called continuous deformations [1,2] (figure 1) or discontinuous deformations [3,4,5,6] (figure 2).

Figure 1. Mining subsidence trough: w – vertical displacement (subsidence) [m], T – tilt [mm/m], R – radius of curvature [km], ε – horizontal strain [mm/m], u – horizontal displacement [m] [1]

In the case of deep mining extraction, i.e. with a depth of over 100-200 m, it is expected that continuous deformations will occur on the surface. These deformations are characterized by mining subsidence trough (figure 1). A characteristic feature of continuous deformations is the continuity of
the subsurface soil layer, in contrast to shallow mining extraction, i.e. with a depth not greater than 100 m (figure 2). Unfortunately, more and more often in the area of the impact of deep mining, also discontinuous deformations of the surface are observed. These deformations most often take the form of the so-called linear discontinuous surface deformations [7], corresponding to the shape of the K, L and N deformations according to figure 2.

Figure 2. Types of discontinuous deformations on the surface in the vertical section observed in the area of the Upper Silesian Coal Basin – (a) surface and (b) linear deformations [8,9,10,11,12,13,14]: A – conical sinkhole, B – truncated conical sinkhole, C – conical-cylindrical sinkhole, D – cylindrical-conical sinkhole, E – bell sinkhole, F – cylindrical sinkhole, G – cuboid sinkhole, H – continuous syncline, I – discontinuous syncline, J – crack, K – fissure, L – fault deformation, M – ditch, N – smoothed ditch

The paper presents the cases of linear discontinuous surface deformations (LDSD), the impact of which was observed in the roadway, presenting their characteristics and impact on the basic technical and operational parameters of the road pavement.

2. Characteristics of linear discontinuous surface deformations (LDSD)
The cause of linear discontinuous surface deformations is the occurrence of significant tensile strains in the subsurface soil layer. These strains are caused by the concentration of the edges of extraction panels, approximately to one plane (figures 3 and 4) [7,4,14] as a result of mining carried out in subsequent seams of the deposit (figure 5). This situation often accompanies the existing so-called safety pillar, created to significantly reduce mining deformations on the protected surface area (figure 5). Unfortunately, as many years of experience indicate, in these areas, there is a significant disturbance of the rock mass structure, which leads to the formation of linear discontinuous surface deformations (figures 3 and 4).

Figure 3. Map of the total thickness of extracted deposit in the vicinity of created linear discontinuous deformations [3]

Figure 4. Edges of ended mining [7]
3. Selected cases of LDSD
A characteristic feature of linear discontinuous surface deformations is a significant disturbance of the original terrain. This is particularly important when referring to areas where linear objects are located, for example, roads and pipelines [5]. The following analysis presents a study of two cases, two different sections of the same road, on which discontinuous deformations occurred. The wheel traffic load should be defined as average (KR4) [15].

3.1. Case A
The road in this section is characterized by a section of 1x2 (one roadway and two lanes) and is located on a hill. The pavement consists of mix asphalt concrete layers, below which there is a layer of slag base. Under the road, mining extraction is carried out. The extraction panels run in a direction almost perpendicular to the road axis - west side and parallel to the road axis - east side (figure 6). The edges of the extraction panels in the subsequent seams form two characteristic planes, on both sides of the mined-out area (figure 6). The measurement of the surface subsidence during the extraction of one of the longwalls (longwall B-4, seam 403/1) indicates the characteristic formation of the mining subsidence trough (figure 7). This means that the extraction of each subsequent longwall will cause tensile strains over a distance of ~ km 189.250-km 189.550. Figure 6 shows the characteristic formation of the mining subsidence troughs over the western edge of the extraction panels located parallel to the road axis. An analogous situation occurs over the eastern edge of the extraction panels located in a direction almost perpendicular to the road axis. The above-characterized location of the extraction panels resulted in the formation of surface thresholds and the accompanying horizontal displacements (figures 8 and 9). Discontinuous deformations are also observed in the area adjacent to the road (figure 10). Deformations in the roadway have deteriorated the longitudinal evenness of the pavement, making it impossible to smoothly travel at the speed of 50 km/h allowed for this class of road. It is worth noting, however, that the measurement of pavement deflections within one of the discontinuities indicates only local weakness of the pavement, i.e. in the immediate vicinity of the linear discontinuous deformation (figures 11 and 12).
Figure 6. Location of mining longwalls and the road axis

Figure 7. Results of the measurements of surface subsidence, period of mining longwall S-2

Figure 8. Discontinuous deformations, the view from the west – case A
Figure 9. Surface threshold – case A

Figure 10. Discontinuous deformations in the area adjacent to the roadway – case A

Figure 11. Location of the measurement section of pavement deflections over the western edge of the extraction panels located parallel to the road axis – case A

Figure 12. Pavement deflections in the measurement section according to figure 11 – case A
3.2. Case B

The road in this section has two roadways and two lanes in each direction, the width of the median strip is approximately 3 m (figure 14). The analyzed section is located at the beginning of the access road to the embankment. The pavement consists of mix asphalt concrete layers and a base of unbound aggregate. There are cohesive soils in the subsoil. On both sides of the road, there are ditches collecting rainwater. The mining situation is characterized by the location of the extraction panels running in the direction almost perpendicular to the road axis. On the eastern side, overlapping edges can be observed that intersect the road axis in the perpendicular direction (figure 13).

![Figure 13](image)

**Figure 13.** The route of the road against the background of extracted panels on the basis [7] – case B

As a result of ended mining extraction, damage to the pavement of both roadways and the median strip were observed. Damage occurred at a distance of about 30 m, taking the form of surface thresholds, which were accompanied by horizontal displacements in the form of fissures (figures 14–17). It is worth emphasizing that the fissures with significant opening were observed in the median strip (figure 17). Characteristic damage was also observed in the ditch, the bottom of which was characterized by areas with no outflow, caused by changes in the vertical alignment (figure 14). The character of the deformation of the bottom of the ditch is described by the vertical alignment shown in figure 18. The measurement of pavement deflections indicates an increase in the value of deflections in the deformation section, especially in the direct location of the discontinuity (figure 18). In view of the observed fissures in the median strip and the water stagnation in the ditch, as well as road pavement cracks, it is worth emphasizing that the pavement deflections may also increase. It results from the reduction of strength parameters of individual pavement layers, including the subsoil caused by rainwater filtration into the pavement and moisture increase.
**Figure 14.** Deformations of the southern roadway – case B

**Figure 15.** Deformations of the northern roadway – case B

**Figure 16.** View of the discontinuous deformations of the roadways towards the east – case B

**Figure 17.** Damage to the roadway and the median strip – case B
Figure 18. Deformation of the road section and the measured pavement deflections – case B

4. Conclusions
The concentration of the edges of the extracted panels, approximately to one plane, leads to the occurrence of deformations on the surface with a course very similar to the course of these edges.

The consequence of the concentration of the edges are surface thresholds and often accompanying fissures. The negative effect of this type of deformation is:

- deterioration of the longitudinal evenness of pavement, which has a direct impact on the comfort of road users, and above all on their safety,
- reduction of the load-bearing capacity of pavement - due to the access of rainwater to the lower layers of the pavement and its subgrade, the stiffness of individual structural layers and the subgrade is reduced,
- deterioration of the longitudinal evenness of pavement requires immediate intervention in order to improve the safety of road users. The reduction of the load-bearing capacity also reduces the durability of the pavement, which in turn leads to a more frequent overlay of the pavement.

In the analyzed cases, there were no geosynthetic reinforcements of the structural layers of the pavement. It should be expected that in the case of their application, the reduction of the load-bearing capacity of the pavement should be smaller. The use of reinforcements should also allow partial mitigation of discontinuous deformations.

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