Change in Stiffness of Pavement Layers in the Linear Discontinuous Deformation Area

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Abstract. The underground mining exploitation causes deformations on the surface of the area which are classified as continuous or discontinuous. Mining deformations cause loosening or compression of the subsoil. Loosening has an impact on the reduction of the subsoil stiffness. As a result the reduction of subsoil stiffness causes loosening of construction layers built in that subsoil. Pavement is a specific case. If there happens to be loosening then the fatigue life of pavement is reduced and premature damages can be observed such as fatigue cracks or/and structural deformation. Discontinuous deformations are an especially interesting case. They not only cause the reduction of the stiffness of the subsoil and pavement layers but also cause rapid deterioration in roughness. Change of roughness is very dangerous especially on fast roads such as a highway. Lately there can be observed the so called linear discontinuous surface deformations in the lanes in the mining area. Unfortunately, the ‘in situ’ research, presenting experiments on the effect of linear discontinuous deformations on the pavement, is in short supply. It is especially crucial with regard to the design of pavement reinforcement and the specification of optimal length of the reinforced part of the road. The article presents the results of ‘in situ’ tests carried out on the chosen pavements where the so called linear discontinuous surface deformation has appeared. The genesis of the damage is connected with the underground mining exploitation. Falling Weight Deflectometer (FWD) has been used in researches. Measuring points were carried out with high frequency which helped to acquire a very interesting distribution of deflections. The distribution of deflections well shows the impact of linear discontinuous deformation on the changes in stiffness pavement layers. In the analysis of data from FWD there has been used back calculation which worked modulus of layers out. The results of researches and analysis have allowed to specify the scale of stiffness reduction of subsoil and pavement layers and, above all, to specify a minimal area of reinforcement. Therefore, the results of the analysis can be very helpful in determining the range of reinforcement as well as designing reinforcement. Of course, researches should be continued for better knowledge about the impact of discontinuous deformations on pavement.

1. Introduction

In the mining and post-mining areas there can often be observed discontinuous deformations. This kind of deformations occurring in the lanes distracts the roughness of the surface which can lead to dangerous situations for the road users. An equally important case is the impact of the resultant surface discontinuity on the changes in stiffness pavement layers and subsoil in its area. The knowledge of the range of discontinuous deformation’s impact on the loosening of the layers (the reduction in their stiffness) will allow to determine the minimum range and the way of repairing the pavement as well as reinforcing the subsoil.
The article presents the analysis of the pavement in which the so called Linear Discontinuous Pavement Deformation (LDPD) has occurred. In the analysis there have been used long-term observations of the area together with the results of measuring points of deflections carried out with the use of Falling Weight Deflectometer (FWD). The results of deflection measurement helped to analyse the distribution of pavement deflections with respect to the LDPD axis. They also helped to carry out back analysis as a result of which layers’ module of Model of Pavement Performance and subsoil have been calculated.

The acquired results of pavement deflection and calculated model pavement module allowed to show the problem of the degradation of the technical condition of pavement layers in the LDPD area.

2. Detailed analysis of the section of the roadway and resultant damages

The section of the roadway in question is situated on the east-west motorway in Poland. It was given to the public use in 2004 and yet in 2005 on the surface of the lane there appeared discontinuous deformation as a result of considerable rock mass movements. The damages in the road took the form of cracking with considerable cracks in them (Figure 1). The crackings were running in the perpendicular-like direction with respect to the road axis. The deformations also appeared outside the motorway lane and these were considerably much greater in intensity (Figure 2). In general, the analysed area is characterised by a very complicated structure of the rock mass and highly intensified impacts of mining exploitation which took place in the past. The mining genesis of the analysed damages has been presented in the publications such as [1-2].

Because of the damages appearing in 2005 the roadway was repaired which brought back the longitudinal evenness of the pavement. The repair was based on the removal of mineral and asphalt layers as well as subbase aggregate layer. Next, the geogrid containing welding nodes was built in and other layers were reconstructed. In the following years the discontinuous deformation was renewed taking the form of sill accompanied locally by cracking (Figure 3, Figure 4, Figure 5). As a result between 2005 and 2015 the pavement was reshape three times. Later repairs (i.e. after 2005) included reshaping the pavement until it reached the depth which enabled the built-in of the levelling layer as well as the surface course made of asphalt mix. The detailed programme of research carried out in 2014-2015 and the following thorough pavement rebuilding allowed to catalogue pavement layers in detail. The average thickness of pavement layers and made ground in the subsoil is as follows:

- 5cm, surface course SMA 0/12,8,
- 10cm, binder course ACWMS 0/25,
- 10cm, base course ACWMS 0/31,5,
- 22cm, subbase course 0/31,5,
- Geogrid containing welding nodes,
- 20cm, technology layer 0/63,
- 20cm, Frost blanket course 0/63,
- Layer of geotextile,
- Geotextile membrane,
- ca. 40cm, Improved subgrade (slag + coarse aggregate)

**Figure 2.** Location of events in the motorway right-of-way and in the adjacent area (Google Earth) [3].

**Figure 3.** Pavement damage 2012

**Figure 4.** Deformation of northern roadway of A4 motorway - 2012

**Figure 5.** Discontinuous deformations of soil surface
It needs to be noticed, however, that the mineral-asphalt package especially was characterised by great differences in thickness which was the result of repair works carried out periodically and the aim of which was to bring back the required roughness of the pavement.

In the end, on the basis of especially georadar researches the differences in thickness of each layer of the Model of Pavement Performance were specified. The thickness of the mineral-asphalt package ranged from 25 cm to 37 cm and the total thickness of wet mix aggregate layers ranged from 128 cm to 138 cm.

3. Pavement Researches

The range of researches included the visual assessment of the condition of pavement damages, pavement deflection measurement as well as georadar researches. This data was completed with the data on the pavement layer thickness during the repair work of the pavement in this area in 2015. Still on the area needs to be regarded as the most crucial pavement damage, the course of which identified the course of LDPD axis. The character of forming the sill should be defined as slow. It is worth noticing that in the LDPD area crackings occurred locally. In the area adjacent to LDPD there could be observed typical top-down cracks in the pavement which reached the binder course.

In order to assess the stiffness of layers which build the pavement layer system, the deflection measurement was carried out with the use of Falling Weight Deflectometer (FWD) (figure 6 ÷ 7). During the measurement, the measuring points were carried out with atypical high frequency from 1m to 10m. As the subsequent deflection analysis showed, the shortening of measuring points allowed to illustrate very clearly the distribution of pavement deflections. In the subsequent stage of analysis of deflection results, it allowed to illustrate the changes in the values of module with respect to LDPD axis.

The weight test of 90 kN was used during the deflection measurement.

4. Results and discussion

FWD measurement allowed to present the distribution of pavement deflections which specifies very well the zone of LDPD impact on the loosening of pavement layers (Figure 8). It can be observed that in the weakest section of the roadway the deflections were over twice the size of those outside the zone of LDPD impacts. It is also worth noticing that the total fluctuation section in the distribution of deflections amounts to about 20m i.e. from 327-706 km to 327-726 km.

In the subsequent stage of the analysis of the results acquired from the pavement deflection measurement, the back analysis was carried out in order to calculate module of pavement and subsoil. The calculations were made by means of iteration method in order to find the values of the module for
the minimum function \((1 ÷ 2)\) [4]. The calculations were done in BISAR 3.0 program. A 3-layered model was used which represented the package of mineral-asphalt layers, the package of aggregate layers as well as the subsoil.

Figure 8. Measured Pavement Deflections

\[ \Delta = \frac{\sqrt{\frac{F}{k}}}{100\%} \]

\[ F = \sum_{j=1}^{k} (w_j - u_j)^2 \]  \hspace{1cm} (1)

\[ w_j \] – displacement calculated in model for distant point - \(r_j\) from load axis

\[ u_j \] – displacement measured on pavement for distant point - \(u_j\) from axis of load

\[ k \] – Number of measured deflections forming deflection bowl

Figure 9. Calculated module for the package of mineral-asphalt layers in the measurement temperature of 15\(^\circ\)C.
In the end, the calculations were made for 30 measuring points. Yet in order to specify the value of module in a single measuring point required carrying out several iterations. The thickness in the Model of Pavement Performance was specified separately for each measuring point on the basis of georadar research. As a result of these calculations the values of module were acquired which are shown in Figure 9 ÷ 11.

![Graph](image)

**Figure 10.** Calculated moduli for the package of aggregate layers.

![Graph](image)

**Figure 11.** Calculated module for the subsoil.

The distribution of calculated module also allows to observe the cause and effect i.e. in the area where discontinuous deformations can be seen on the surface (Figure 3 and 4) there can be observed the reduction of the values of the module with respect to the adjacent points which are away from the deformation axis (327+713km) for about 10m. Having assessed the values of the module it is worth noticing that the modulus of mineral-asphalt package in the deformation zone is characterised by the values typical of the cracked structure. In the package of aggregate layers the acquired module in the damage zone reach the values of even 40 MPa which are very low for aggregate layers. Even the module of the subsoil in this zone are higher (min. 102 MPa). Outside the deformation zone all three layers of the model pavement are characterised by very high values which prove quite low values of pavement deflections for +15°C (Figure 6) and the weight of 90 kN.

Having assessed a very low modulus of the layer which represents aggregate package, the fact seems to be very important that in this package there is a layer of geosynthetic (geogrid with welding node) situated at a depth of about 20cm from the surface of the whole aggregate package. At this stage of research it seems to be a justified statement that as a result of deformations in the subsoil, there occurred the loosening of the construction layers built in this subsoil. Yet, the geosynthetic placed in the upper part of the package of aggregate layers minimised the deformation in the aggregate above it and...
at the same time limited the possibility of the geomattress layer to be adjusted partly to the lower parts of aggregate after the subsoil deformation came to an end. In this way between the geosynthetic layer and lower aggregate layers there occurred cracks (empty spaces) the effect of which can be observed in the form of lower module for the whole package of aggregate layers. Of course, a slight stiffness of the geomattress does not allow the layer to obtain mechanical as well as geometrical features. That is why despite slight rock mass movements after 2005, as a result of geosynthetic’s creep, there occurs a very slow but continuous deformation of the pavement in this area.

5. Conclusion

The above case of the pavement situated in the area of discontinuous deformations presents very well the range of impact of such kind of deformations on the subsoil and construction layers of the pavement. As the results show, the zone of loosening in the deformation area reaches the length of about 20m.

Discontinuous subsoil deformations caused the loosening of both the subsoil and the aggregate layers placed on it, causing deformations and crackings in the mineral-asphalt package. It needs to be noticed, however, that these deformations indeed were muffled because of the use of geosynthetic which unfortunately with time got adjusted to the form of lower loosened and deformed remaining aggregate layers.

The fact that the geosynthetic was used, which slowed down the process of pavement deformation, had a considerable impact on the safety of the road users. The case presented in this article can become a basis for further consideration as to the way and range of pavement protection in the discontinuous deformation area.

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