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Research paper

Influence of mining operations on road pavement and sewer system – selected case studies

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ABSTRACT

Underground mining operations cause surface deformations which influence structures. A particular group of structures which are susceptible to the influence of mining operations are so-called “linear objects”, whose characteristic parameter is their length. Linear objects consist of, for example: roads, rails, sewers and water supply systems. Changes in the length of measurement bases (deformations) accompanying mining deformations and changes in ordinates, including the difference in subsidence (inclination), to a large extent determine the utility properties of the structures and create a significant nuisance when using them and even causing them to fail completely. It is worth emphasising that when applying proper preventive measures once continuous deformations have begun, it is possible to use the objects for a relatively long period of time. In the case of discontinuous deformations, the utility properties are significantly deteriorated, which most often leads to failures, significantly hastening the decision to conduct repair works.

This article presents selected cases of the continuous influence of mining operations on a sewer system and of discontinuous deformations on a road pavement. The presented research and *in situ* observations may be useful in assessing, designing or re-building such structures in areas where mining operations are planned.

1. Introduction

Linear objects are highly susceptible to changes in soil parameters, which is particularly important in mining areas (Bell & Donnelly, 2006; Bell, Donnelly, Genske, & Ojeda, 2005; Kalisz & Zięba, 2014; Kay, 2012; Mikulenka, 2007; Żak, Chlipalski, & Strycharz, 1995). Mining deformations cause changes in the geometric parameters of linear objects and changes in soil conditions, as well as in the strength parameters of the very materials the linear objects are built of (Chlipalski & Strycharz, 2000; Kay, Whelan, Donald, & Pinkster, 2007; Luo, 2015; Muszyński, Kalisz, Stefańska, Gruchlik, & Rogusz, 2005). Similar changes may be caused by the construction of shallow underground tunnels in urban areas (Donglin, Xin, & Yusheng, 2014). Linear objects include road pavements and technical infrastructure objects, i.e. sewer systems, water supply systems or gas pipelines.

The technical condition of a road pavement is described with parameters which characterize its load-bearing capacity (fatigue strength of pavement), evenness, determine comfort and safety, frictional properties and surface qualities. Considering the specific conditions for roads in mining areas, mining deformations have overwhelming influence on their load-bearing capacity and the evenness of the pavement, with distinguished longitudinal and traverse evenness. The load-bearing capacity of a pavement ought to be associated with its fatigue strength, i.e. the number of equivalent standard axles which cause characteristic damage to the pavement – fatigue cracks and/or structural ruts. Assessment of the influence of mining deformations on the pavement is analysed based on the distribution of the deflections of the whole system, consisting of layers of the pavement and soil, or the distribution of the values of modules of given layers in a pavement model. In road network management systems, the load-bearing capacity of a pavement is assessed based on a so-called deflection index, determined based on the measurements of pavement deflection, e.g. using Falling Weight Deflectometer (FWD). Depending on the load caused by pavement motion, this being one of seven categories of movement, the calculated index of deflection falls into one of four classes of load-bearing capacity (A to D), based on the current boundary values (Dąbrowski et al., 2015). Class A represents the parameters of a new road pavement, and class D the condition of pavement which requires immediate repairs.

Pavement evenness determines to what extent the road pavement surface is concurrent with a flat surface. Of course, changes in the surface depend on the stiffness of the road pavement, and in mining

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areas, additionally, on the course of soil deformations. Longitudinal evenness is described using the International Roughness Index (IRI) expressed in mm/m. Following Polish regulations, which concern the assessment of existing pavements (Dąbrowski et al., 2015), the IRI ought to fall within the range of 2 mm/m and 5.7 mm/m, and, as for load-bearing capacity, there are four levels of quality. Class A characterises good condition (new pavements), and class D means bad condition. Determining the evenness class does not only depend on the measured and calculated IRI but also on the road class. In mining areas, the pavement is particularly sensitive to changes in evenness in the area of discontinuous deformations.

The article presents two examples of roads of different classes, where discontinuous deformations referred to as Linear Discontinuous Surface Deformations (LDSD) were observed. In these examples, changes in the distribution of surface deflections in the LDSD zone are presented and deflection indices are calculated (Dąbrowski et al., 2015). For the higher class road (case A), through applying IRI, parameters of longitudinal evenness were also determined.

Apart from the influence of mining deformations on road pavements, this article also presents the influence of continuous mining deformations on sewage system infrastructure.

As far as roads are concerned, they can be accompanied by surface water drains and sanitary sewers, and sometimes combined sewer systems. A gravity sewage system consists of pipelines, and a combined pressure and gravity system also contains sewage pumping stations and pressure pipelines.

The pipelines are influenced by horizontal displacements and deformations of the near-surface layer of soil, as well as area curvatures, which may play an important role in large cross-section pipes. Uneven horizontal displacements and deformations of soil result in additional displacements and deformations, as well as additional forces and bending moments acting on pipelines (Luo, Peng, & Chen, 1998). Excessive displacements and deformations of pipelines may lead to the exceeding of serviceability limit states through the unsealing of pipe joints, a decrease in the cross-section area, or even the closing of the cross-section area and blockage of the flow. Forces and bending moments may cause limit states of load-bearing capacity of pipelines to be exceeded, which results in damage to the walls and joints of pipes and fittings. The influence of underground mining operations on linear objects is presented, in a simplified form, in Fig. 1.

The minimal and maximal slopes in gravity sewers are strictly determined. Minimal slopes are determined for the lowest sewage flow velocity, which ought to be maintained to ensure sewer self-cleaning. The velocity, for sanitary sewers and surface water drains, when the cross-section is filled up, is 0.6–0.8 m/s, and for combined sewers, 1.0 m/s (Służalec, 2012). Providing such a level of velocity requires the maintenance of proper minimal slopes, which depend on the shape and dimensions of a sewer's cross-section as well as the type of pipes. The minimal slope of a sanitary sewer, for pipes with a nominal diameter of DN 200 mm, is 5‰, and for passable sewers of DN ≥ 1000 mm it is assumed to be 1‰. The maximal value of a slope ought not to result in excessive flow velocity as this may lead to increased wear on the pipe walls. The velocity for sanitary sewers built of concrete and clay pipes is 3.0 m/s, and for pipes made of reinforced concrete, cast iron and plastic it is 5.0 m/s. Maximal flow velocity for combined sewers and surface water drains is 7.0 m/s (Służalec, 2012). Analyses of slopes in sewer systems and concerned with forecast mining deformations are conducted through comparing actual slopes of given sewer sections, determined basing on geodetic measurements, with acceptable or forecast values of surface inclinations. The values of slopes i in a sewer and changes in them in mining areas ought to then meet the following condition

$$i_{\min} \leq i \pm T \leq i_{\max} \tag{1}$$

where:

$i_{\min}$ – acceptable, minimal value of slope,
$i_{\max}$ – acceptable, maximal value of slope,
i – actual slope of a sewer, determined based on measurements,
T – value of changes in surface inclination along the pipeline.

2. Influence of continuous deformations on pipelines

The issue of mining impact on sewers was presented based on the influence of continuous ground deformations. These deformations can cause:

- damage to the structure of sewers,
- unsealing of sewers,
- damage to the structure of manholes,
- unfavourable changes in slopes.

The influence of horizontal soil displacements and strains together with surface curvatures causes damage to the walls of pipes and their joints, as well as the relative displacement of the pipes. Mechanical damage in clay and concrete pipes, which make up the majority of pipes in the older sewer systems in mining areas in Poland, takes the form of cracked walls, cracked sockets and broken sockets. In areas of extensive

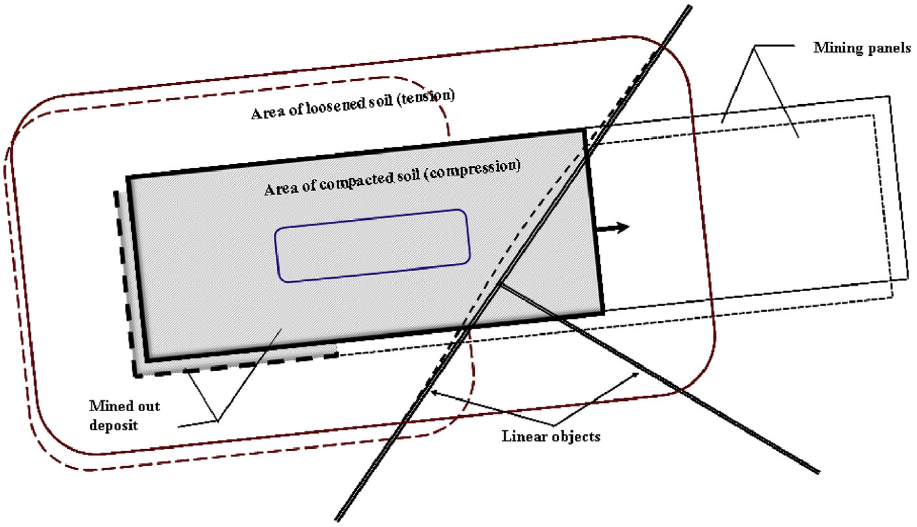


Fig. 1. Schematic influence of mining operations on linear objects.

cracking, cross-sections of sewers are often deflected and even cave in. Slides and traverse pipe displacements are also effects of mining operations, causing pipelines to unseal. An example of such damage to a concrete sewer is presented in Fig. 3. Manholes can also become damaged; the watertight connection bells in a manhole base crack and the manhole concrete sections crack and get unsealed. The integrity of a sewer system structure is of utmost importance and should be assessed first in mining and post-mining areas. Assessment of this type of damage to sewers in mining areas is descriptive and can be conducted using periodic video inspections of sewer systems (Petrushin & Khan, 2007).

In areas of significant damage, which render further use of whole sections of the system impossible, it is still possible to determine the length of the damaged area and its share u_u in the total length of the tested sewers

$$u_u = \frac{l_u}{L} \tag{2}$$

where l_u is the length of damaged sewers.

If value u_u is divided by a specific time Δt, expressed in years, we receive the damage intensity index λ_u

$$\lambda_u = \frac{l_u}{L\Delta t} \tag{3}$$

It ought to be emphasised that index λ_u is not determined here based on the amount of damage (Hotloś & Mielcarzewicz, 2011; Kwietniewski, Roman, & Kłos-Trębaczkiewicz, 1993), which is hard to assess for sewage pipelines in mining areas. It is based on the length of damaged sewers, which cannot be used any longer. It is a much more pragmatic approach.

Surface inclination is one of the indices of ground deformation which describes a continuous subsidence basin. The index may cause unfavourable changes in the slopes of sewers, lowering their hydraulic efficiency. A decrease in slopes to values below the minimum leads to blocks which require unclogging. In some parts of sewers, counterslopes occur leading to sagging which causes sewage to build up and leads to the flooding of manholes. Such situations occur particularly often in areas where multiple mining operations take place, when, as a result of their overlapping influences, significant surface subsidence occurs. An example of a sewer with a nominal diameter of DN 200 mm whose profile underwent significant unfavourable changes resulting from intensive, multiple mining operations is presented in Fig. 2. After the occurrence of mining deformations, in a large part of the existing sewer shown in Fig. 2 counterslopes occurred, which were determined basing on geodetic measurements. Values of the counterslopes were between 0.0‰ and 18.0‰ along a distance of approximately 210 m, which, in turn, formed sagging of approximately 270 m.

It must be mentioned that in the analysed section, according to the documentation, the initial values of the slopes of a sewer between manholes were close to or equal to the minimum value, i.e. they were 5.0–6.0‰ (the minimum value for the sewer is 5.0‰). Thus, it can be concluded that the sewer could not possibly deal with the forecast surface inclinations, which may be treated as violating the rules of building sewers in mining areas. At such values of unfavourable changes in slopes, up to -26.0‰, caused by mining operations, a sewer system ought to be designed with a pump system, transferring sewage to a pump station situated in the lowest forecast point in the area.

Based on the issue described concerning changes in the slopes of sewers during and after the occurrence of mining deformations, the influence of the deformations on changes in slopes in sewer systems can be characterised through determining sections with improper slopes (reversed, too low or too high) in the analysed area. This is done using geodetic measurements of ordinates for the manhole bases and the determination of the slopes in the sections of the sewers between the manholes. Results of the measurements enable the determination of the share of the sections of the sewers with improper slopes u_s across the total length of analysed sewers

$$u_s = \frac{l_s}{L} \tag{4}$$

where:

l_s – length of sewers with improper slopes,
L – total length of the analysed sewers.

If value u_s is divided by specific time Δt, expressed in years, an index of the intensity of changes in slopes λ_s, is obtained and can be applied to characterize the reliability of sewers in mining areas (Hotloś & Mielcarzewicz, 2011; Kotowski & Kluska, 2000).

Damaged sewers along the streets of Śródmieście and Załęże, two districts of Katowice, prior to their repairs and rebuilding are good examples of damage to a sewer system (Muszyński et al., 2005). The systems were built without securing them against mining soil deformations. Coordinated multiple mining operations in the area of Śródmieście, Katowice, were conducted between 1970 and 1995. Most of the combined sewer system was built there in 1907–1935 of clay and concrete pipes. In Załęże, the sewer system, built mainly in 1907–1937,

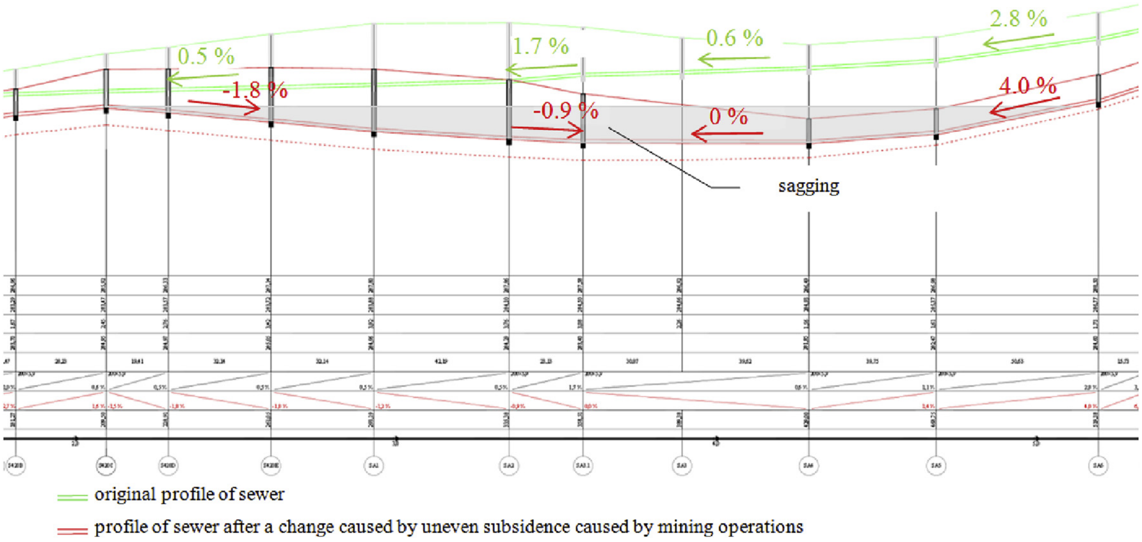


Fig. 2. Examples of changes in the profile of a sewer caused by multiple mining operations.

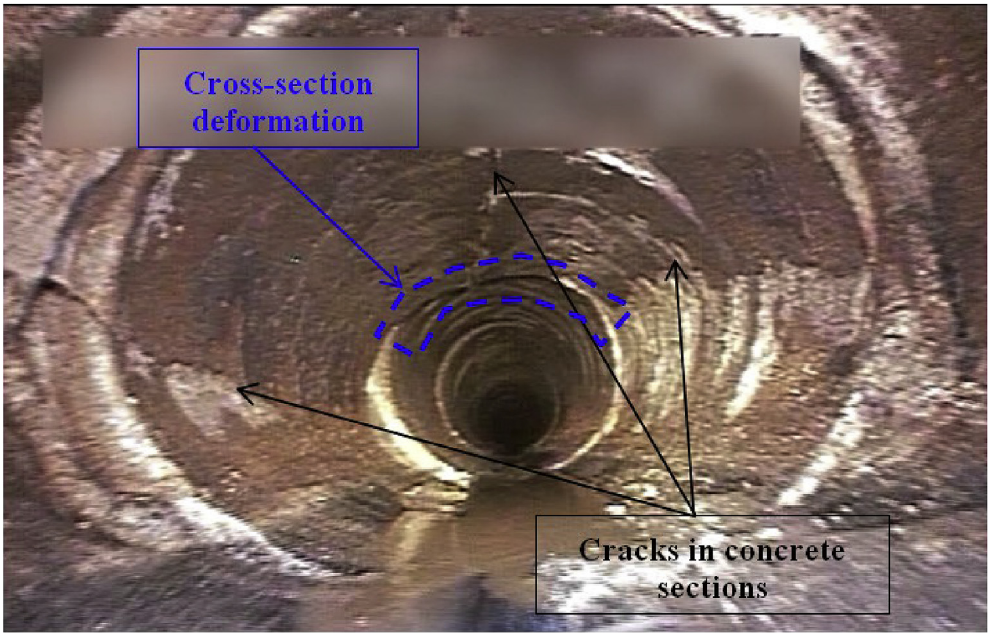


Fig. 3. Example of damage to a sewer built of concrete pipes.

also of clay and concrete pipes, was influenced by mining operations which lasted from 1907 to 2000.

The share u_u of the damaged sections for the remaining part of the sewers of proper slopes in Śródmieście and Załęże, Katowice, was determined to be 90–100% for clay pipelines and 80–90% for concrete pipelines. The high proportion of damaged sections in the analysed system resulted from the fact that sewers were not secured against mining surface deformations.

Using geodetic measurements conducted for 11.35 km of the combined sewers along the streets of Śródmieście, Katowice, improper slopes occurred along 2.10 km of them, thus their share was $u_s = 18.5\%$. The average index of the intensity of changes in the slopes of sewers was $\lambda_s = 0.0074$ km/km/year.

The geodetic measurements conducted for the length of 7.87 km of combined sewers along the streets of Załęże indicated that improper slopes occurred in 3.13 km of the sewers, thus their share was $u_s = 39.7\%$. The average index of the intensity of changes in the slopes of sewers was $\lambda_s = 0.0051$ km/km/year.

3. Influence of linear non-continuous surface deformations on road pavement

In mining areas, pavements are subjected to the influence of continuous and discontinuous mining deformations. The influence of continuous surface deformations is manifested in the form of loosened soil and loosened layers of pavement. These changes lead to the decreasing stiffness of the whole pavement and the shortening of the period of service between repairs (Grygierek & Grzesik, 2011). The deformations do not cause any significant changes in pavement evenness. Discontinuous deformations are a particularly unfavourable example of mining deformations. They are accompanied by both a decrease in stiffness of the pavement and changes in longitudinal evenness, posing a threat to the safety of drivers. Discontinuous deformations are more and more often observed in Polish roads and are called linear discontinuous surface deformations. In spite of the fact that they are an increasingly common phenomenon, it seems they have not been sufficiently described in the literature, especially the aspect of their influence on the decrease in stiffness of the construction layers of a pavement and/or soil (Grygierek & Kawalec, 2016; Grygierek, 2017).

Linear discontinuous surface deformations (LDSDs) result from the concentration of the edges of mining panels in roughly one vertical plane. Most often LDSDs take the form of bumps and cracks (Kowalski, 2015), which significantly deteriorate pavement evenness, posing a threat to drivers, especially on high-speed roads, e.g. motorways. This article describes two cases of the influence of LDSD on a road pavement.

The first one (A), presenting the influence of LDSDs on a lane, is the section of the A4 motorway in Poland, near the rest and service area (RSA) Halemba and Wirek (Fig. 4). The road pavement transmits the significant load of heavy vehicles and consists of the following layers:

5 cm, wearing layer SMA 0/12.8,
10 cm, binder BAWMS 0/25,
10 cm, base BAWMS 0/31.5,
22 cm, aggregate base 0/31.5,
heat-welded geogrid,
20 cm, subbase 0/63,
20 cm, frost protection 0/63,
geotextile,
geomembrane,
approximately 40 cm, improved subgrade (slag + coarse-grained aggregate),
subsoil – residual clay.

As a result of mining operations (Fig. 5), whose origin was described in detail by Kotyrba and Kowalski (2009) and Kowalski (2015), there was damage in the form of a bump and cracks in the pavement and in the adjacent area (Fig. 6).

Characteristics of the mining deformations, which appeared in the motorway lane in the years 2002–2014 are presented in Figs. 7–9.

Due to the fact that a bump was consistently recurring, the road pavement was profiled through adding a compensatory layer and a wearing layer. Periodically, the road pavement also underwent geodetic measurements together with measurements of pavement deflections (Fig. 10) and longitudinal evenness. Finally, approximately 200 m of the road pavement was characterised using the results of *in situ* measurements, i.e. distribution of deflections on both lanes, calculated deflection indices and the IRI.

$$DST = D_0 \cdot (50/F) \cdot f_T \cdot f_S \cdot f_P \tag{5}$$

where:

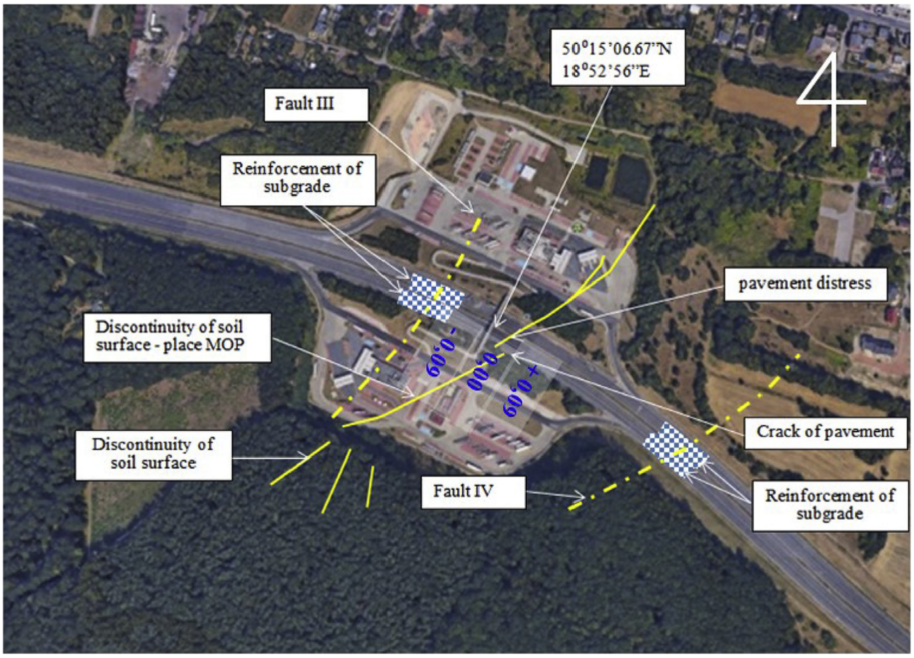


Fig. 4. Situation in the area of LDSD – motorway A4.

DST – standardized deflection,
D_0 – measured deflection,
f_T – coefficient of temperature,
f_s – coefficient of season (June, $f_s = 1{,}12$),
f_p – coefficient of subbase (flexible pavement, $f_p = 1{,}0$).

$$U = \frac{\sum_{i=1}^{n} us_i}{n} + D_u \tag{6}$$

where:

U – deflection index (a standardized reliable deflection),
us_i – standardized value of a single deflection measurement,
n – number of standardized deflections in the road section,
D_u – standard deviation of the standardized values of single deflection measurements in the reliable section.

The results of deflection measurements enabled the detailed analysis of the weakened pavement in the approximately 10-metre-long area of the LDSD, where an over two-fold increase in road pavement deflection ($u > 0.50$ mm – Fig. 11, Fig. 12) was observed in relation to the adjacent area of the homogeneous distribution of deflections ($u < 0.20$ mm) and the area beyond the LDSD zone. However, it is worth noting that the deflection indices calculated based on measured deflections (Fig. 13) indicate the class of the technical condition to be at least B (5)–(6). Such a relatively good result can be explained by the fact that the deflection index is a value representing a 50-metre-long section. The relatively good result of longitudinal evenness IRI (class B) could be explained in a similar way (Fig. 14)..

Based on the results presented, it can be observed that applying standard rules of assessing the condition of pavements, e.g. deflection index and IRI, does not adequately reflect the local weakening of the pavement (stiffness decrease – deflection increase) (Fig. 13) and the significant disturbance in longitudinal evenness (Fig. 14).

The other case (B), which presents the influence of LDSDs on road pavement, is the pavement of a regional road with medium traffic load, but located in an area of much more intensive mining operations than in the first case. Increased activity means here more frequent mining operations, whose influence is manifested in the discussed section of the

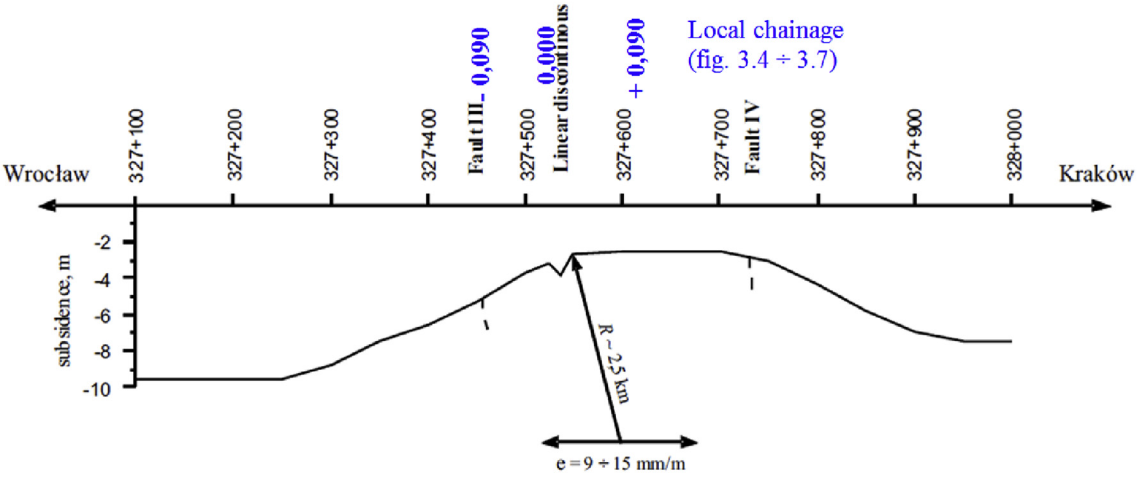


Fig. 5. Subsidence of surface along the axis of highway A4 before commencement of construction works in the area of faults III and IV, due to mining operations and estimated horizontal deformation ε (Kotyrba & Kowalski, 2009).

Fig. 6. Deformations observed on the surface and in the area of LDSD (Grygierek & Kawalec, 2016).

road and through greater surface subsidence. Just like in the first case, the origin of the observed discontinuous deformations is associated with overlapping edges of mining panels (Fig. 15) and the concentration of the "edges" of further subsidence basins (Fig. 16), which are accompanied by convex curvature and tensile deformations (Fig. 16). The road pavement consists of the following layers: a package of asphalt-aggregate mixture layers of 30 cm, a package of aggregate and slag of approximately 30 cm.

In case B, only deflections were measured and longitudinal evenness was not. The distribution of deflections (Fig. 18) in case B is very similar to the one observed in case A (Figs. 7 and 8). There is a significant increase in deflections over a relatively short distance of approximately 5 m. The conducted assessment, based on deflection index (Fig. 19), shows the pavement to be at least of technical condition class B, which indicates its high stiffness. It is worth observing that in the assessed section there are cracks which were primarily associated with the strains generated by the rock mass movements and to a lesser extent with the influence of traffic load. This observation is also confirmed by the traverse direction of the cracks (Fig. 17).

4. Discussion

Underground mining operations, by causing deformations in the near-surface layer of the rockmass, influence structures by subjecting them to additional loads. The presented examples of the influence of continuous mining deformations on sewers indicate their high susceptibility to the changes in surface inclination. The changes in the slope and, therefore, gravity associated with these mining deformations in sewers transporting wastewater or stormwater, may limit their performance and even lead to blockages. This is associated with the occurrence of counterslopes and so-called sagging (Fig. 2). In such cases it is necessary to implement pressure and gravity sewer systems, which would not be necessary in areas without the influence of mining operations. Moreover, in continuous deformations there is also additional load exerted on sewers resulting from the influence of horizontal displacements and strains. The additional earth pressure which is associated with this, may cause deformations in the cross-section of sewer elements and even lead to mechanical damage and the unsealing of sewers.

Indices determined based on equations (2)–(4) can be applied to assess the scope of the damage to sewer systems, because they provide information on the share of the sewers damaged, as a result of mining operations in the whole system, and the average increase in the amount of damaged sewers per year. However, it must be emphasised that it is hard to clearly recognise the damage caused by non-mining factors, e.g. the influence of traffic. This is possible with a comparative method which considers the damage sensitivity of sewers with similar construction and commissioning date in areas without mining influence (Zuber, 1999). Using such comparisons, it is only possible to assess the share of the influence of mining operations in mechanical damage, occurring in sewer systems in mining and post-mining areas. The situation is much more straightforward for changes in slopes, although the issue of proper system development at the design and construction stage also has to be considered.

Taking into consideration the fact that sometimes it is not possible to foresee the influence of mining operations which may occur a few decades later, in mining areas developing optimal sewer systems designed for at least a few decades of service is much more challenging. Therefore, the owners, in cooperation with mining enterprises, ought to perform periodic measurements of the slopes of sewers and monitor the

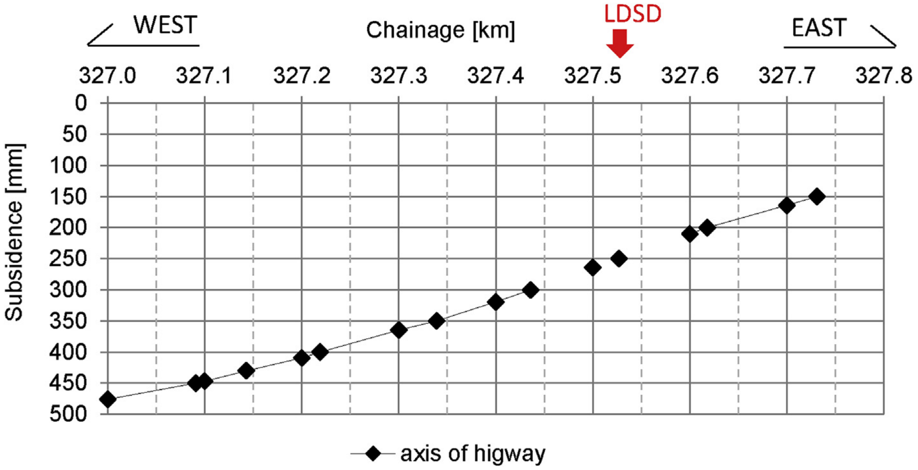


Fig. 7. Reprognosed surface subsidence in the years 2002–2014.

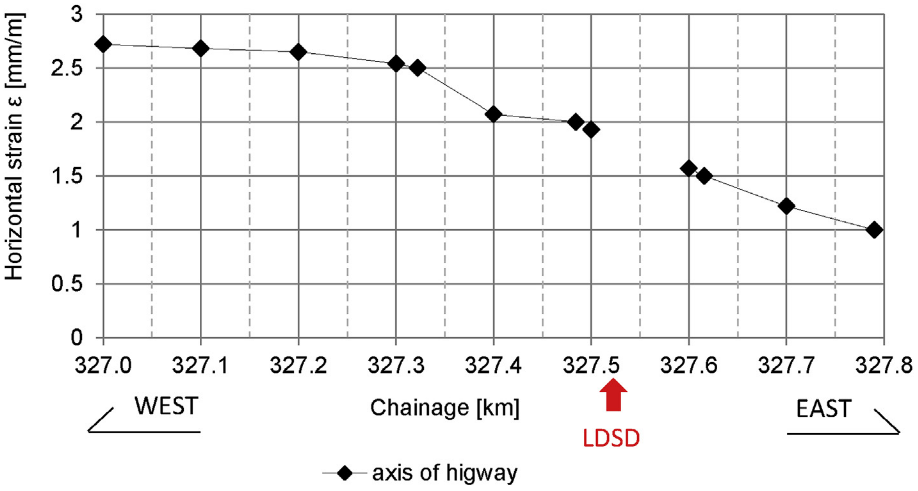
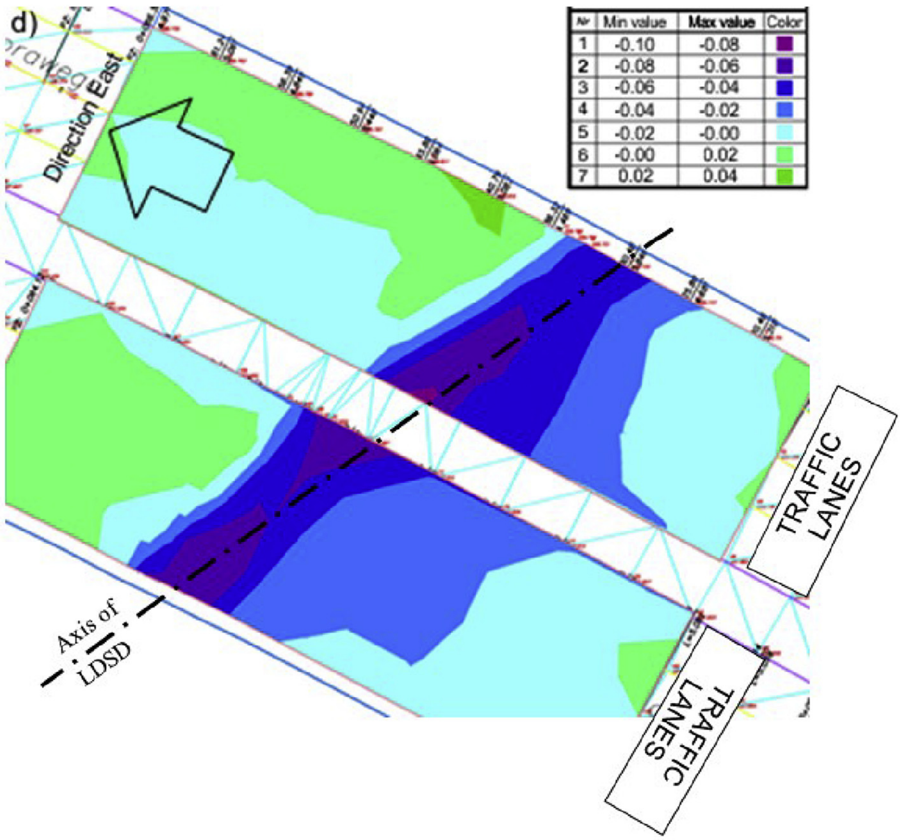


Fig. 8. Reprognosed horizontal soil strains in the years 2002–2014.

technical condition of the infrastructure within sewer systems influenced by mining operations; additionally, if necessary, they must take necessary actions (Francini, 2011; Report, 2008, 2017).

In roads and the analysed influence of linear discontinuous surface deformations on the pavement layers and soil, relatively short sections of lowered stiffness are formed (Fig. 11, Fig. 12, Fig. 18). The two presented examples: A and B, show that their length does not exceed 10 m. Yet, it was concluded that when applying the methods of monitoring the pavement of a road network, which are currently binding in Poland, such short weakened sections generally do not result in the negative result of pavement assessment, which is expressed with the class of technical condition. The class is determined based on reliable deflection, which is the total of the average measured deflection and the standard deviation for the whole analysed section (50 m). In the area of LDSDs, much more attention ought to be paid to the problem of emerging unevenness, which most often takes the form of even a few-centimetre-high bumps (Fig. 14). Such bumps pose a real threat to the safety of road traffic, especially on high-speed roads (motorway – case A).

In the areas of the LDSDs, there are limited possibilities to counter their negative consequences. The bump ought to be “levelled”, which is associated with applying so-called geomattresses and “sliding” layers underneath. There are also known concepts of applying jointed reinforced concrete slabs in such zones. Yet it has to be emphasised that



Nr	Min value	Max value	Color
1	-0.10	-0.08	🟪
2	-0.08	-0.06	🟪
3	-0.06	-0.04	🟦
4	-0.04	-0.02	🟦
5	-0.02	-0.00	🟦
6	-0.00	0.02	🟩
7	0.02	0.04	🟩

Fig. 9. Map of the required range correction of grade line – year 2014.

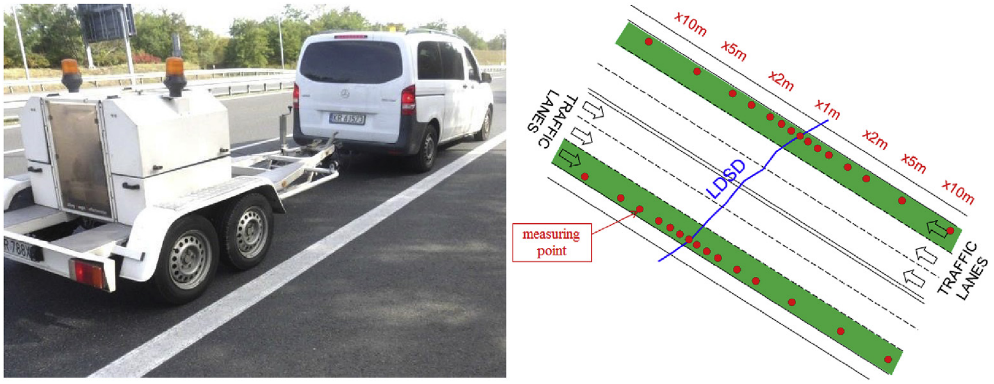


Fig. 10. Distribution of the measuring points of pavement deflections in the LDSD zone.

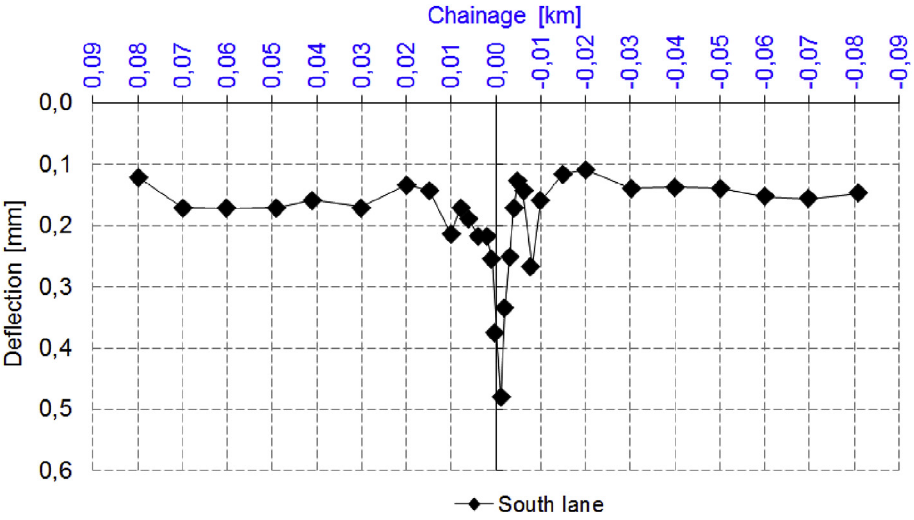


Fig. 11. Distribution of measured pavement deflections, south lane (test load 90 kN).

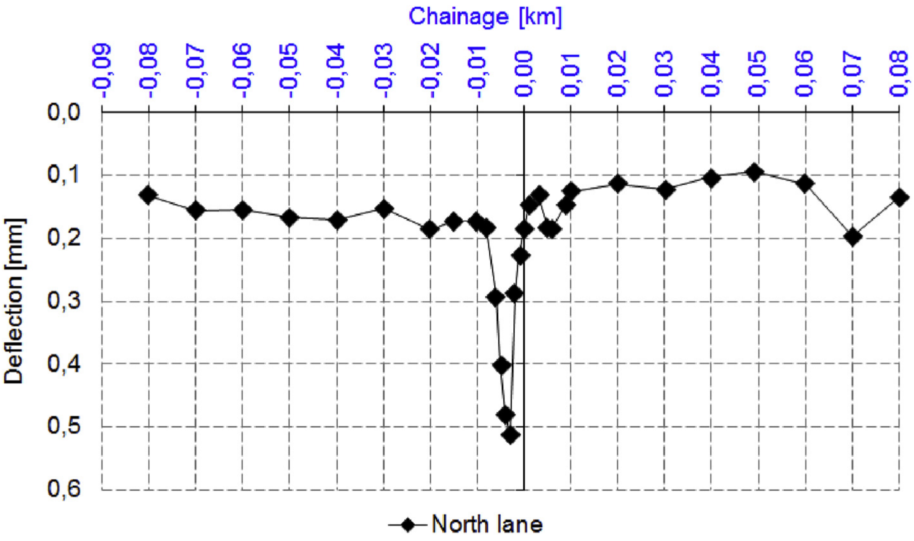


Fig. 12. Distribution of measured pavement deflections, north lane (test load 90 kN).

the solution only minimises the negative consequences of emerging discontinuous deformations.

5. Conclusions

Mining operations influence sewer systems, causing unfavourable changes in the slopes of sewers and damage to the elements of the system. The influence of horizontal soil displacements and strains, and curvatures cause damage to the walls of pipes and their joints, as well as the relative displacement of the pipes, causing leaks. The above presented examples of the mining influence on gravity sewers also indicate their high susceptibility to changes in the slope. This may significantly

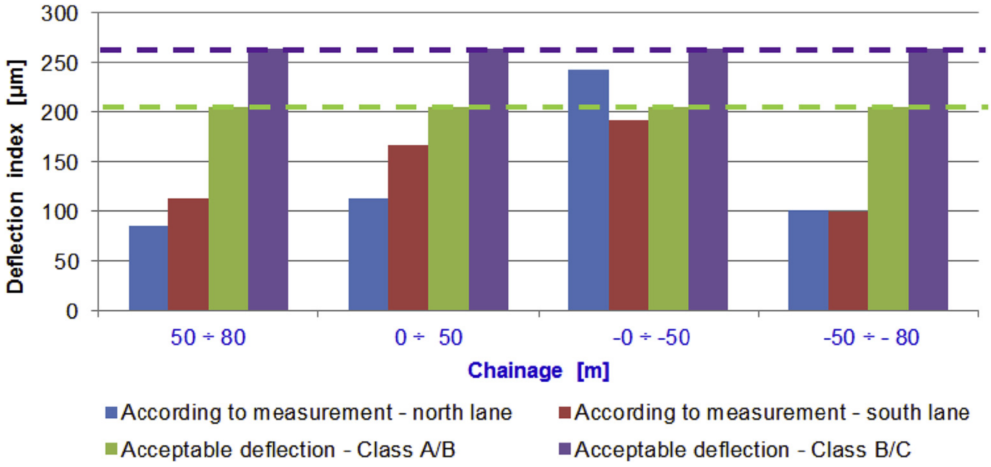


Fig. 13. Deflection index of pavement loaded with traffic, KR6-7.

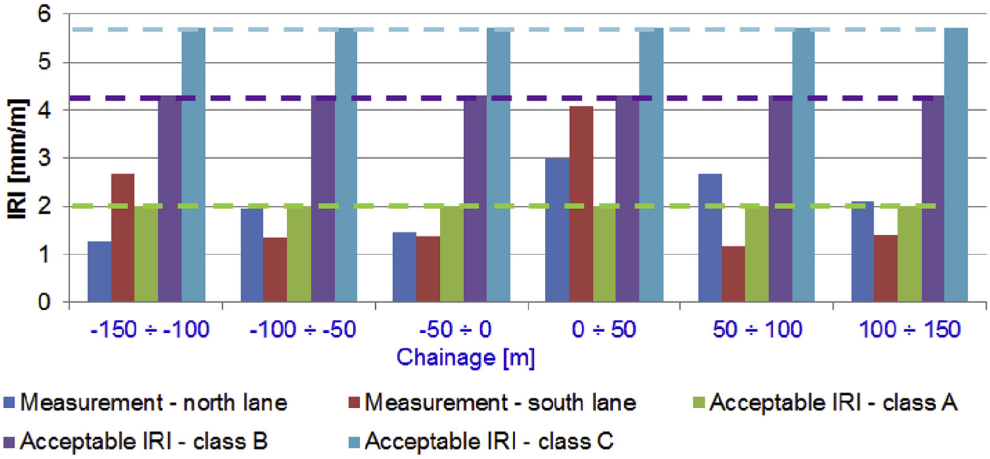


Fig. 14. Distribution of international roughness index (IRI).

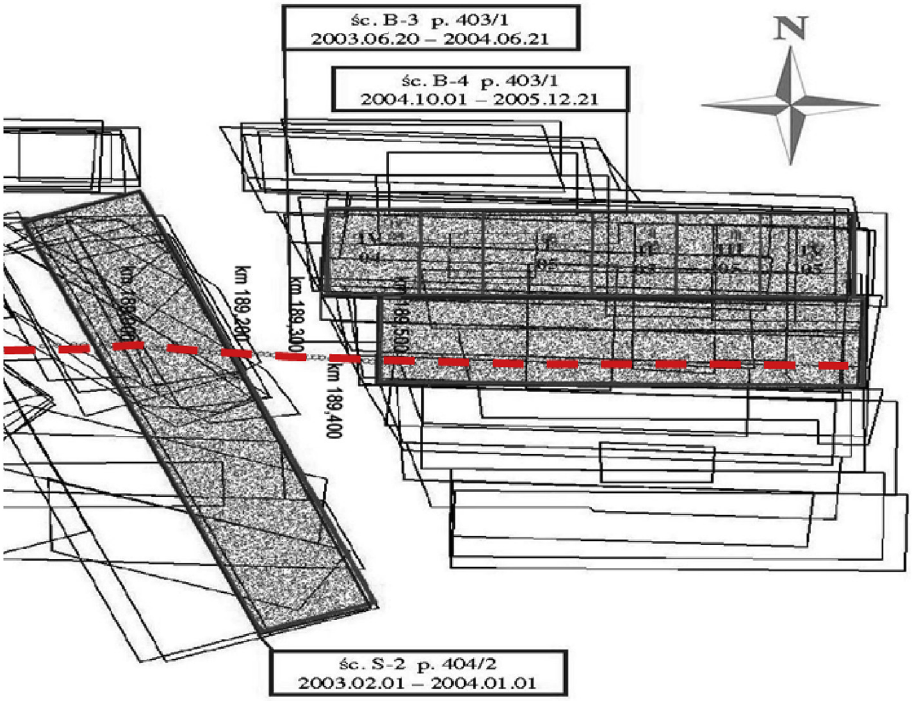


Fig. 15. Distribution of mining plots and the axis of the road.

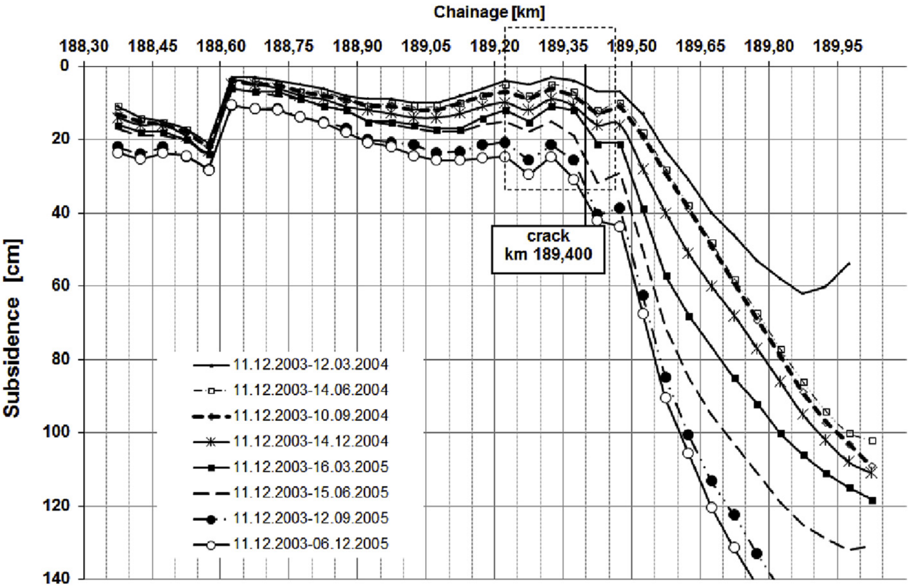


Fig. 16. Results of measurements of subsidence, period of mining longwall S-2 (according to Fig. 9).

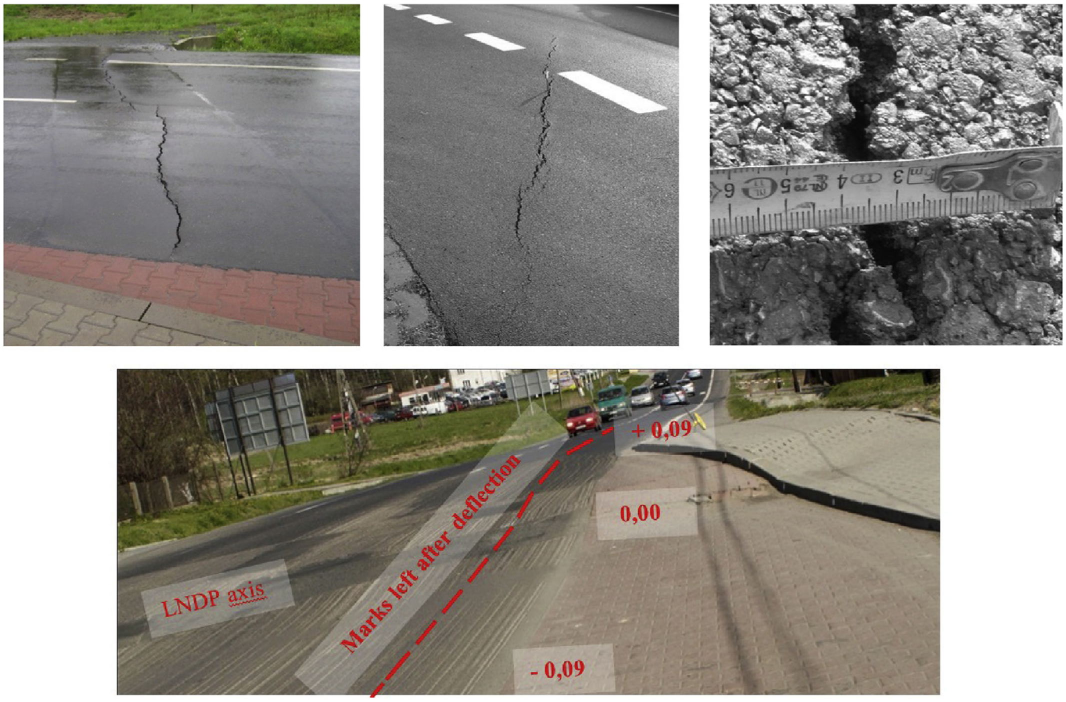


Fig. 17. Damage to different surfaces in LDSD zone and in adjacent sections.

limit their performance and even lead to blocking the flow of wastewater and stormwater. This results in lowering the performance of sewer systems in mining areas. That is why, while designing and building new sewer systems, a specific approach is required. It ought to consider:

- applying safety measures in sewers and other objects of the system (e.g. pipes embedded with extension joints, manholes with reinforced walls),
- applying extension joints, which ought to be of a proper length, adjusted to the length of the pipes and forecast values of horizontal soil deformations, as well as area curvatures,
- applying flexible pipes (polyethylene) in pressure piping, which are capable of absorbing deformations of the near-surface layer of soil,
- building gravity sewers with proper extra slope,
- the optimal location of a sewage pumping station.

Further research should be conducted in mining areas to determine the share of damaged sewer length in the total sewer length and the value of the damage intensity index. The main goal of this research is to assess the influence of ground deformations on the different types of gravity sewer construction. The results should help to determine favourable solutions for the construction of sewers in mining areas.

In an area where linear discontinuous surface deformations (LDSD) occur, the construction layers of road pavement are significantly weakened. However, the weakened section is relatively short. On the basis of the knowledge and experience presented in this paper it can be stated that:

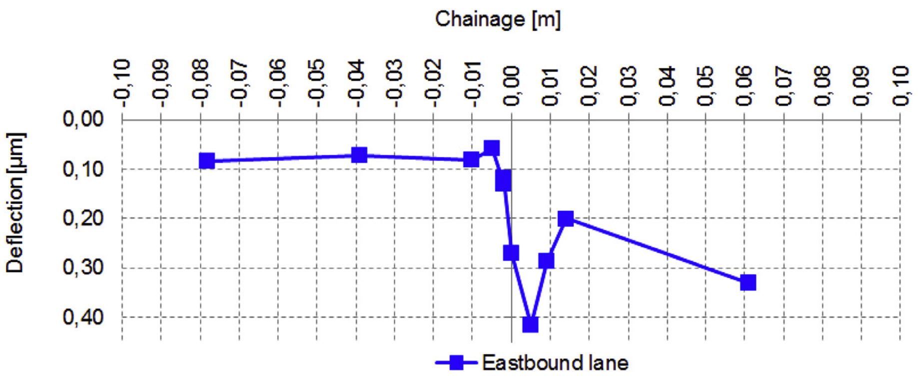


Fig. 18. Distribution of pavement deflections (test load 50 kN).

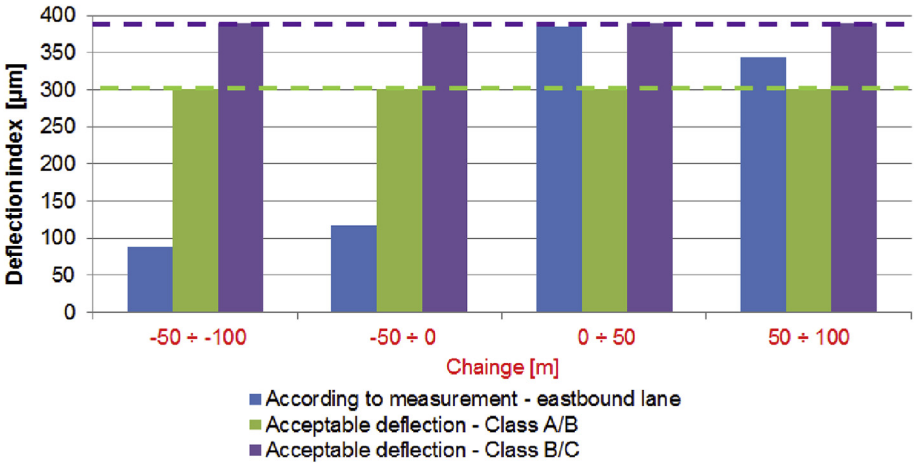


Fig. 19. Deflection index of pavement loaded.

- there is an increase in pavement deflection in a 10 m section in the LDSD zone,
- the maximum value of pavement deflection in the LDSD zone is twice that of the deflection of pavement outside the LDSD zone.

The observed increase of unevenness (IRI index) and pavement deflection in the 10 m section of the LDSD zone has a small amount of influence on standardized deflection describing the load bearing capacity state of pavement calculated for a 50 m section. The standardized deflection is calculated every year for pavements of road networks.

A much more serious problem is the bumps accompanying LDSDs, which jeopardise the safety of drivers, especially on high-speed roads.

The presented issues should be the subject of further research to estimate changes in the parameters of pavement construction elements. For example, knowledge of changing the parameters of the pavement model in the mining impact area would allow for more effective selection of mining and construction prophylaxis.

Conflict of interest

None declared.

Ethical statement

Authors state that the research was conductedaccording to ethical standards.

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