Designing, execution and using stage of highway A4 (E40) based on active geological fault

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Abstract

Highway A4 (E40) runs from the east to the west of Poland. One part, which was built in years 2002-2003, goes through the Silesia Region which is strictly connected with mining activities. Many years of mining extraction have left a significant influence on the road usage. The most unique effect, which became a foundation of this article is a geological fault which crosses the highway near Katowice City. This article summarizes nearly 15 years of the highway existence at the fault, starting from designing process through execution stage, use stage up to renovation which was made in 2015. Great database illustrates step by step the propagation of fault and its influence on the road. The paper presents researches and designing negligence that has been made through many years, but also describes latest renovation solutions which were taken in 2015. The article focuses on the issues of very high tensile strength geosynthetic reinforcement structure and cyclic geodetic monitoring system which was made to ensure safety of highway users.

Introduction

The final decision about localization of Silesian highway A4 section was taken in 14 January 1998. In 1999 the complete geotechnical documentation for more than six kilometers long section (from 325+232 km to 331+470 km) had already been done and the designing process could be started. After four years, in 2003, works on building site began, and lasted up to 2004. Finally, after nearly six years of investigation process, the highway was ready to use in January 2005.
The issue could be considered to be closed if the highway surface hadn't been seriously damaged which occurred in the first year of its use. A crack, on both sides of the road, appeared in 2005 near "Halemba-Wirek" service areas (figure 1). Soon after, the crack transformed into vertical displacement (fault) which become a serious danger for highway users.

Figure 1. Cracks on the highway surface 2005.

Localization

Considered section of the highway goes through the Silesia Region which has been and still is strictly connected with mining activities. The highway runs through several active coalmining areas (figure 2). Many years of mining extraction have left a significant influence on subsoil which is a base for highway construction. The subsoil become degraded by continuous and discontinuous ground deformation caused by mining activities. Discontinuous deformations occur, among others, as geological faults. There are about eight catalogued faults at the considered section. Two of them (number III and IV) are located near the place where the crack occurred.

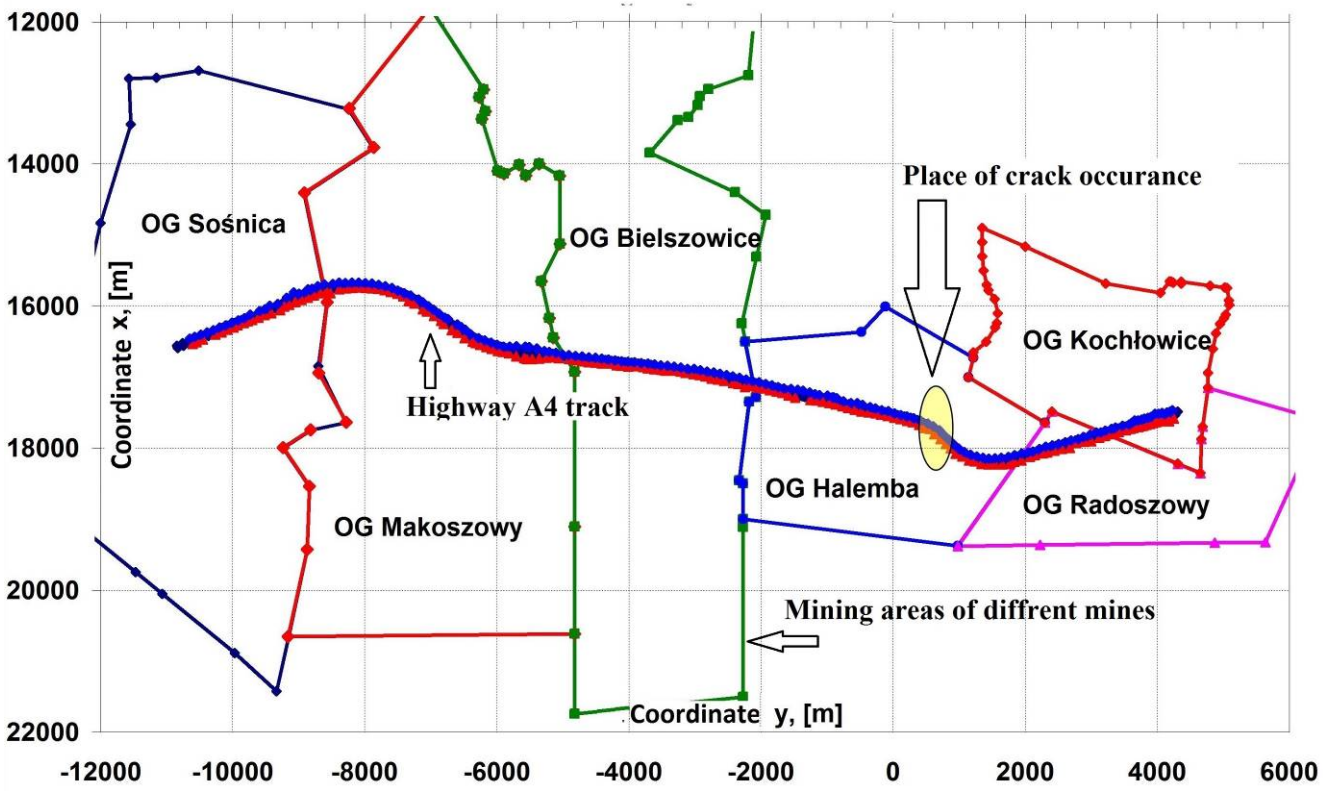


Figure 2. The track of the A4 highway going through mining areas – section Gliwice - Chorzów

Figure 3. Estimated localization of the faults III and IV

Designing process.

Designing process was based on the Geotechnical Documentation from 1999. The authors of the article concentrate only on the motorway subsection, were the cracks appeared. The subsection is between 327+350,00 km and 328+000,00km, where the road goes in deep excavation. Unfortunately the subsoil recognition process didn't take this fact into account. The geological boreholes were made too shallow (figure 4).

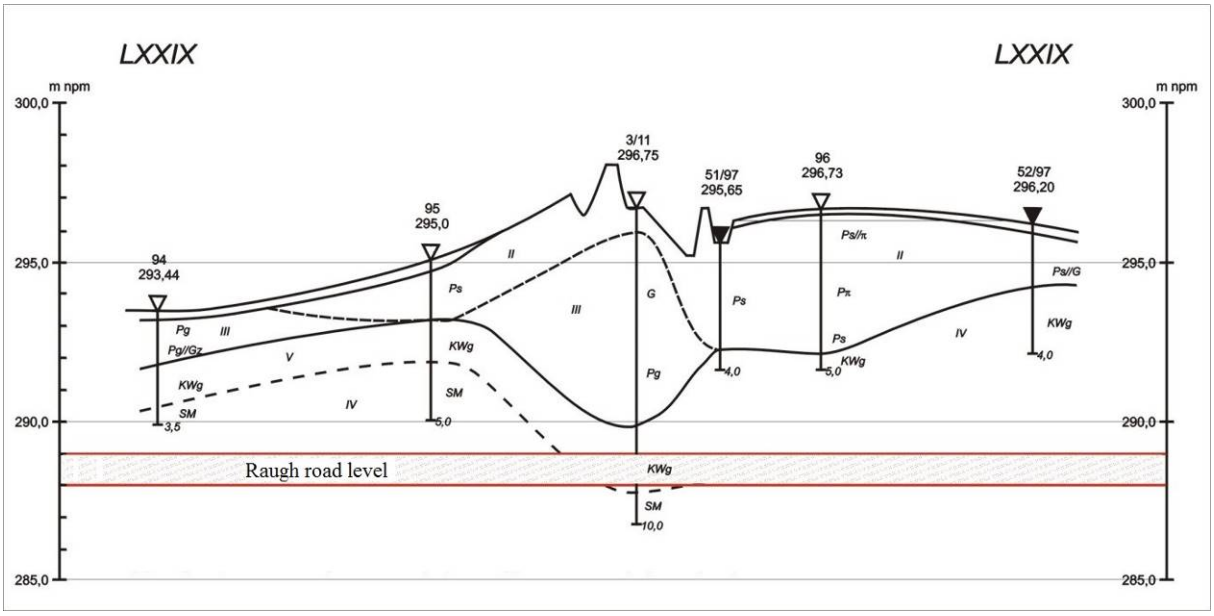


Figure 4. Geological cross section based on the geotechnical documentation from 1999.

This issue had not been resolved at the designing process and the highway construction had been designed on unrecognized subsoil.
According to the authors of this paper also the problem of mining activity was downplayed. The project involves unified geosynthetical reinforcement on the whole section. The reinforcement was applied regardless of ground conditions or the scale of mining activities influence on the subsoil. Designers suggested the reinforcement should be in a form of two layers of stiff monolithic geogrids with integral junctions (figure 5).

Figure 5. Original reinforcement provided for mining influence at the A4 highway (section Ruda Śląska – Chorzów).
Photo made in 2015 during the renovation.

Designers decided to change the reinforcement only just above the suggested localization of the fault III. The modification covered only 5,0m width of the highway. Two extra layers of low-tension stiff monolithic geogrids were added (altogether there were 4 layers of geogrids). According to the authors, these changes were insignificant in comparison to the occurred situation.

Execution stage

In October 2003 the excavation works were advanced. As a result of observed variability of the ground, the contractor commissioned an additional ground investigation. Geophysical works were made, and they become a base for reinforcement expansion. The expansion in the area of suggested fault III localization, included the modification of ground layers thickness and the modification of the range for designed two additional layers of geogrids (enlargement from 5,0 m to 54 m on the north roadway and from 5,0 m to 78 m on the southern roadway). Geogrids material - polymer and its strength were not changed.

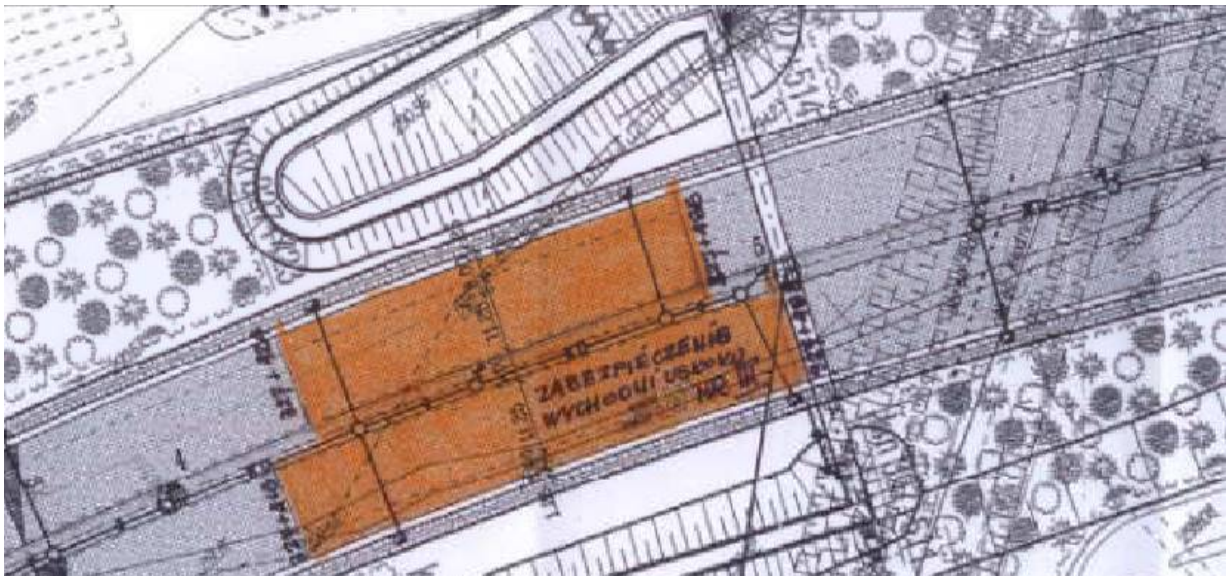


Figure 6. Range of additional reinforcement in estymatet fault III area.

Contractor and designers noticed another disturbing signals when excavation works were done. Sinkholes and local depression appeared on the highway base ground, as a result of heavy rainfalls in May 2004. The depression location did not correspond with the estimated fault III localization. The comparison can be seen on satellite image (figure 7). This image dates May 2004 - depression outline can be seen.

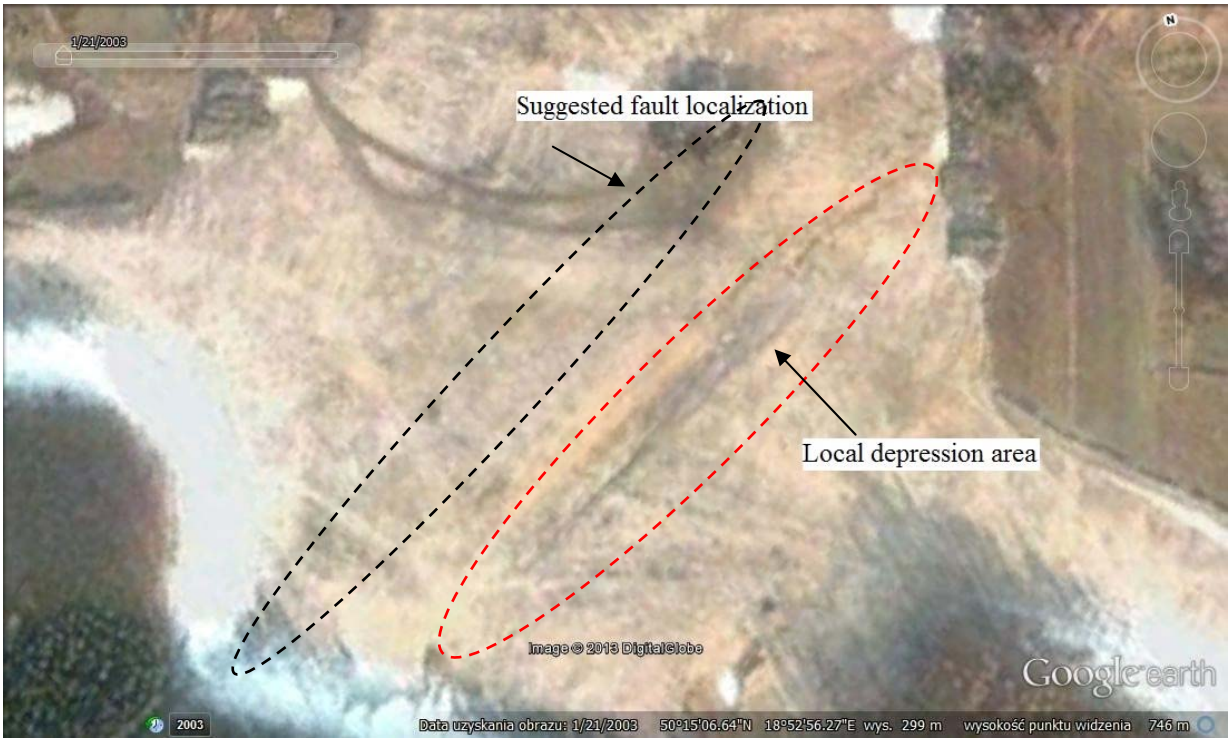


Figure 7. The local depression area on building site after heavy rainfalls.

Unfortunately this situation was neglected, and the cause of the problem had not been found. Sinkholes and local depression had been buried, the reinforcement type and even the range of it had not been changed.

Outcome

In 2005, right after the highway was given to use, the crack on both sides of the road appeared. Shortly after the crack transformed into gaps and next in a little vertical displacement. As it can be seen by comparison figure 1 and 7, the crack occurred exactly at the place where the local depression occurred during construction stage.

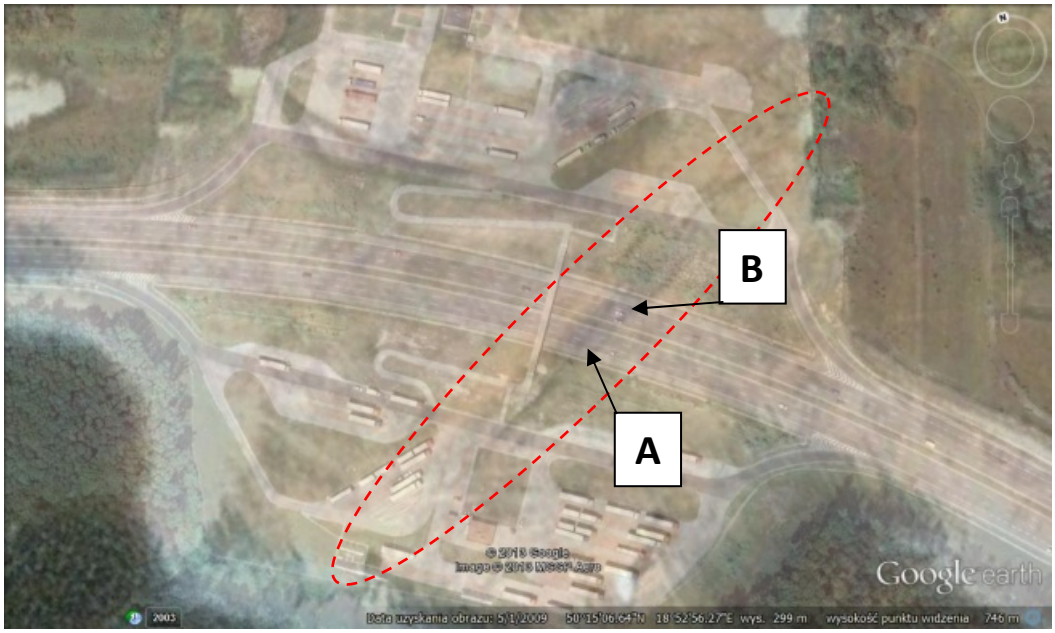


Figure 8. Location of the local depression plotted on the highway satellite photograph.

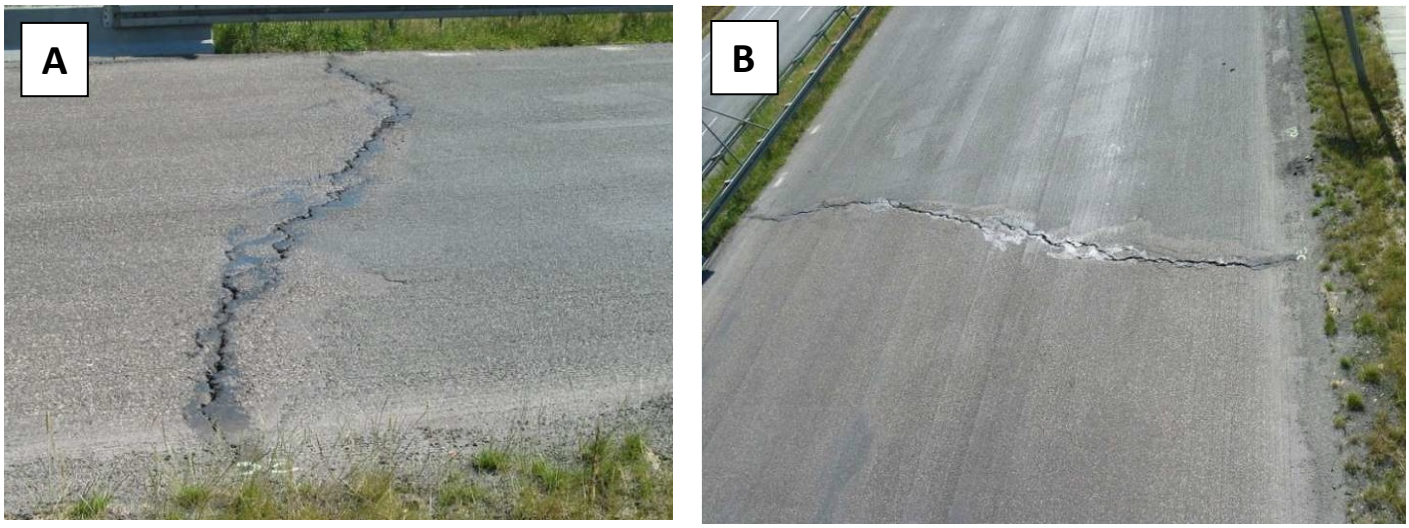


Figure 9. The crack which occurred in 2005.

During the building phase, due to the active mining exploitation, a geodesic monitoring was realized. Measurements in fault III area are shown on figure 10.

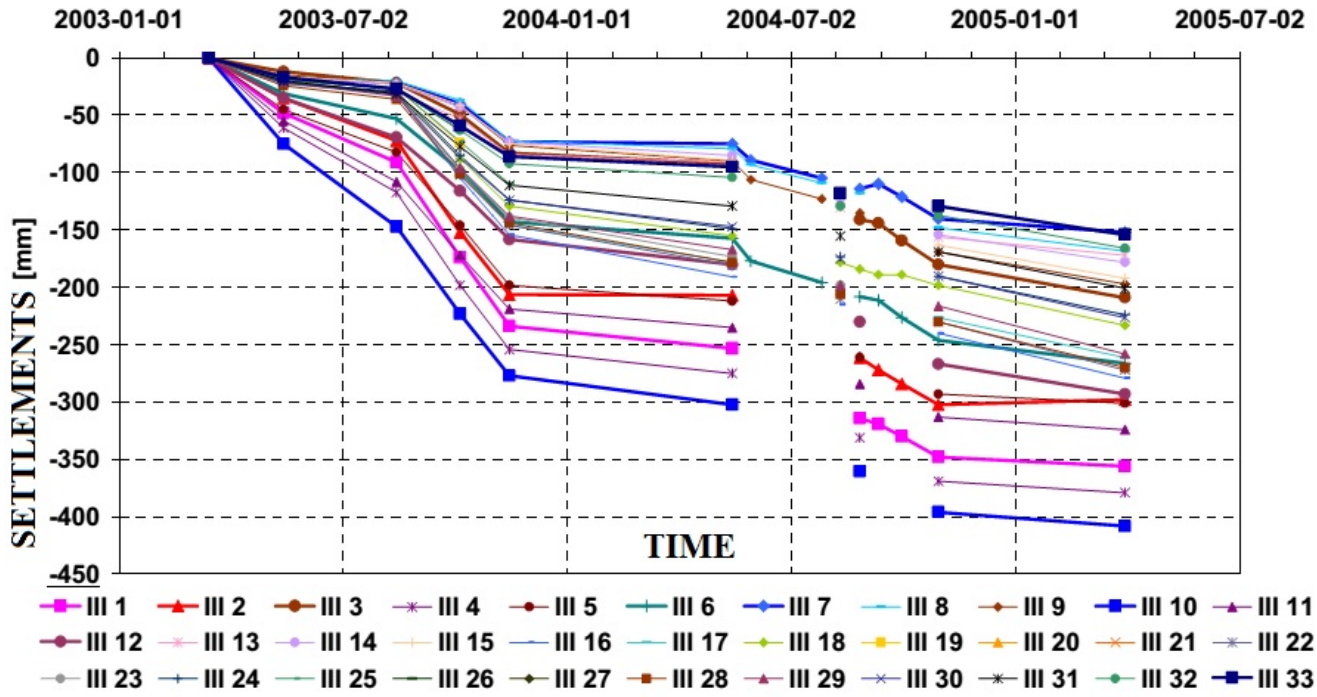


Figure 10. The geodesic monitoring measurements in fault III area.

As it can be observed, settlements increase significantly in period 2004-2005, exactly at the time when crack occurred.

The highway damage become the beginning for several treatises and associated ground investigation (geophysics and FWD). Finally as a result in 2007 highway was repaired.
The repair action included removal of asphalt layers (2 meters width on each site of the crack) and removal aggregate layers to 0,44m depth. Designers provided reinforcement as a two layers of stiff monolithic geogrids (ultimate tensile strength 40 kN/m), tied together with still pins (figure 11).

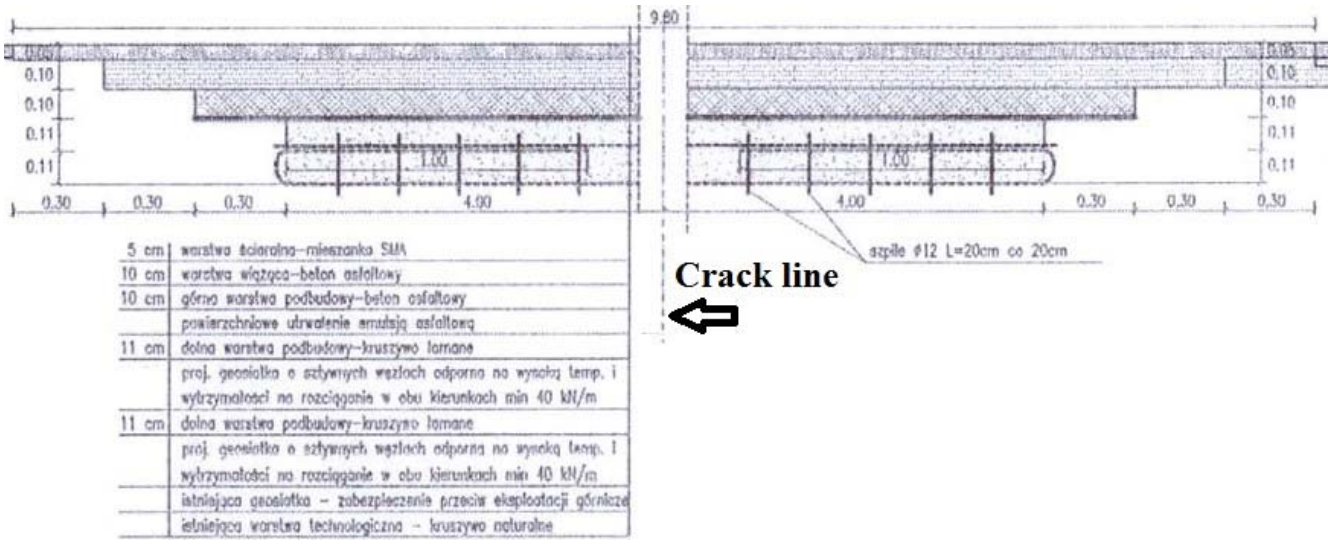


Figure 11. Rapair project from 2007.

The geodesic monitoring has been stopped in 2005 when in subject area mining activities were already done. Authors think that the highway administration assumed that the discontinuous deformation problem was solved and fault will not propagate in the future. As a result there is lack of information about settlements in period from second half 2005 up to 2010.

Less than two years after renovation, in May 2009 discontinues deformation occurred again. A place of occurrence was corresponding with damage from 2005.

Figure 12. Discontinuous deformation raised in first half of 2009.

Worth to noticed is highway surface behaviour. This time discontinuous deformation did not cause crack or gap in asphalt layers (figure 12).

At the beginning the deformation has been downplayed. The highway administrator did not take any repair action, only the travelling speed has been limited. The vertical deformation increased over the time. This state lasted up to end of 2011, when the administrator took the decision about reparation. In 2012 geological surveys and Falling Weight Deflectometer examinations were started. In that time vertical difference between both sites of the deformation amounted about 9 cm (the volume was not equal on highway width, 9 cm was the highest difference). In 2012 layers of asphalt still were not broken.

Research results

The executed geophysics recognition allowed to predict that discontinuity under the highway had developed. At figure 13 resistance differences can be seen.

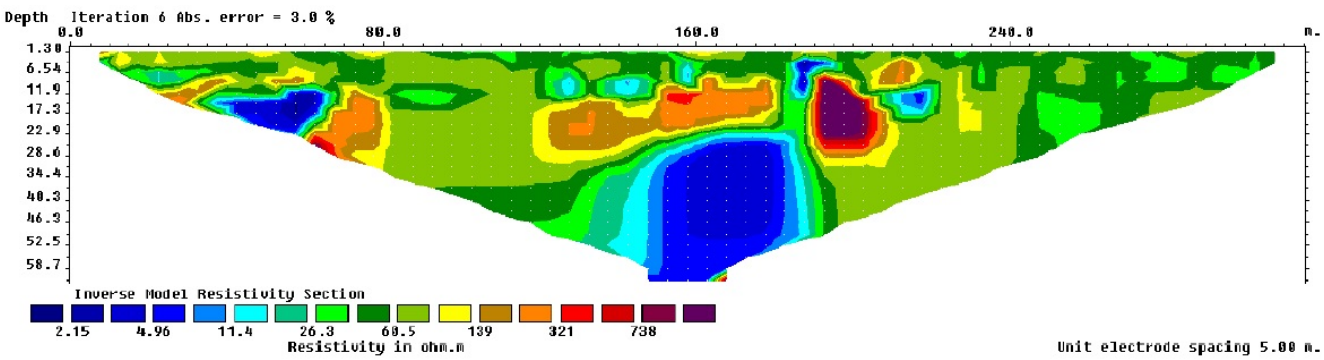


Figure 13. Resistance differences in the highway subsoil.

Landform in the area around highway, can confirm the hypothesis. Figures 14 and 15 were taken in 2012, and illustrated discontinuous deformations caused by mining activities.

Figure 14 and 15. The landform caused by mining activities. Localization in a forest near to highway.

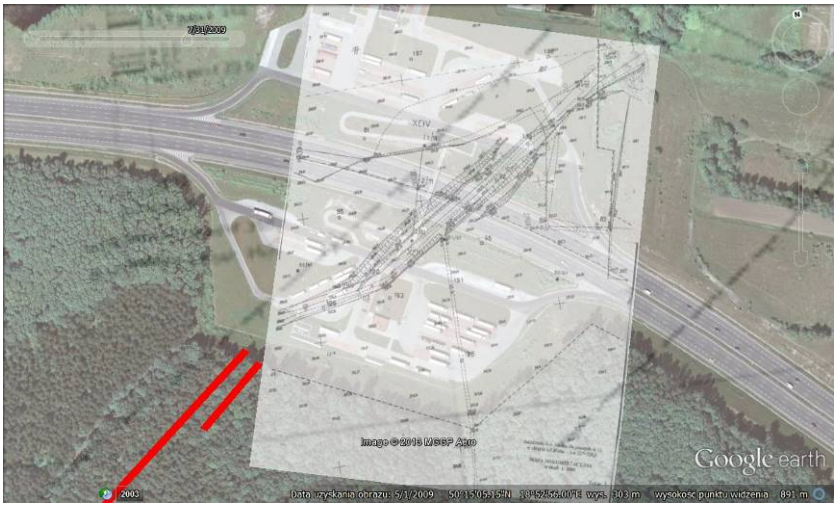


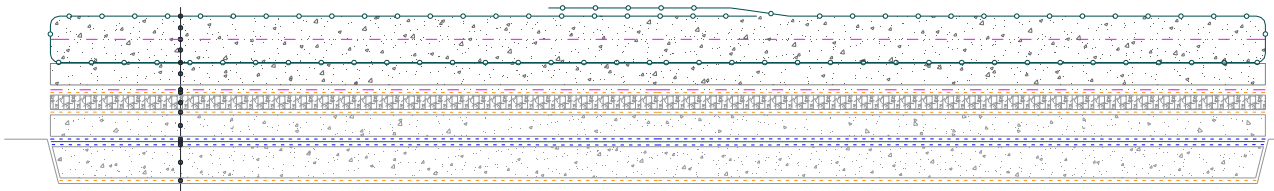
Figure 16. The landform(figure 14,15) localization – red lines

Repair second attempt

A highway renovation project, made based on geological surveys, was ready in the end of 2012. For the first time suggested solutions were supported by calculations. The vertical drop on level 10 cm was assumed to the calculations. The project provided three equivalent solutions adopted for the highway protection.

a) The first conception assumed geogrids reinforcement, installed on reinforcement concert platform.
b) The second conception assumed high-strength aramid geogrids reinforcement, installed on "slide surface" made from geomembrane.
c) The third and the last conception assumed grillage made from reinforcement concrete anchored on reinforcement concrete piles.

Finally, form economic reasons, the road administrator the chose second conception for implementation. Years 2013 and 2014 were spend for formal issues connected with conception choice and contractor selection. Ultimately in 2015 repair works had started.



	High strength aramid geogrid (Fortrac R1200/100-30AT) - laid perpendicularly to highway axis
30,0cm	Mix aggregate 0/63 mm
	High strength aramid geogrid (Fortrac R1750/100-30AT) - laid parallel to highway axis
30,0cm	Mix aggregate 0/63 mm
	High strength aramid geogrid (Fortrac R1200/100-30AT) - laid perpendicularly to highway axis
30,0cm	Mix aggregate 0/63 mm
	High strength aramid geogrid (Fortrac R1750/100-30AT) - laid parallel to highway axis
	Non-woven geotextile 4 class CBR
20,0cm	Gravel 4/16 mm in cell geogrid
	Non-woven geotextile 4 class CBR
30,0cm	Crushed aggregate 0/63 mm
	Non-woven geotextile 5 class CBR
	Geomembrane 2 mm
	Non-woven geotextile 5 class CBR
50,0cm	Crushed aggregate 0/63 mm
	Non-woven geotextile 4 class CBR

Figure 17. The approved reinforcement construction.

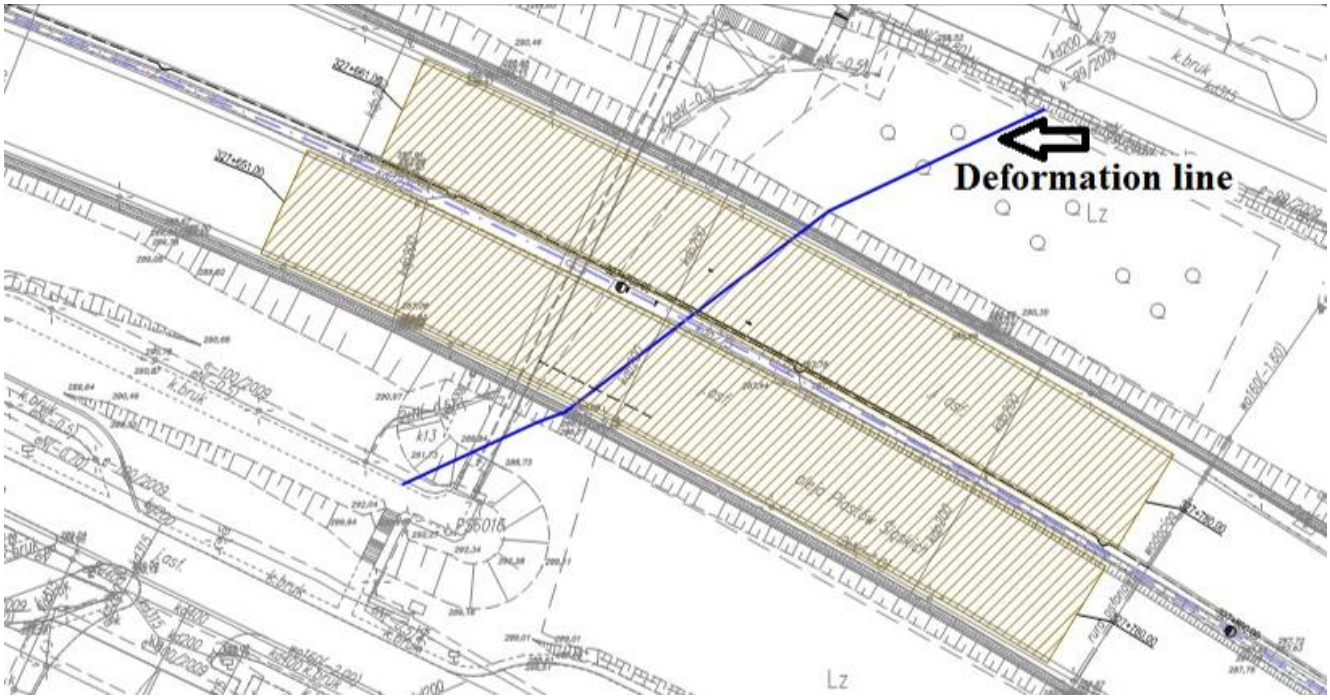


Figure 18. The reinforcement range

Figure 19 and 20 Geogrid installation process with tension strength measurement.

Figure 21 and 22 The reinforcement installation process.

Conclusion

Finally in the end of 2015 construction works have been completed. The highway is in use up to now without failure, despite the mining activities have been resume.

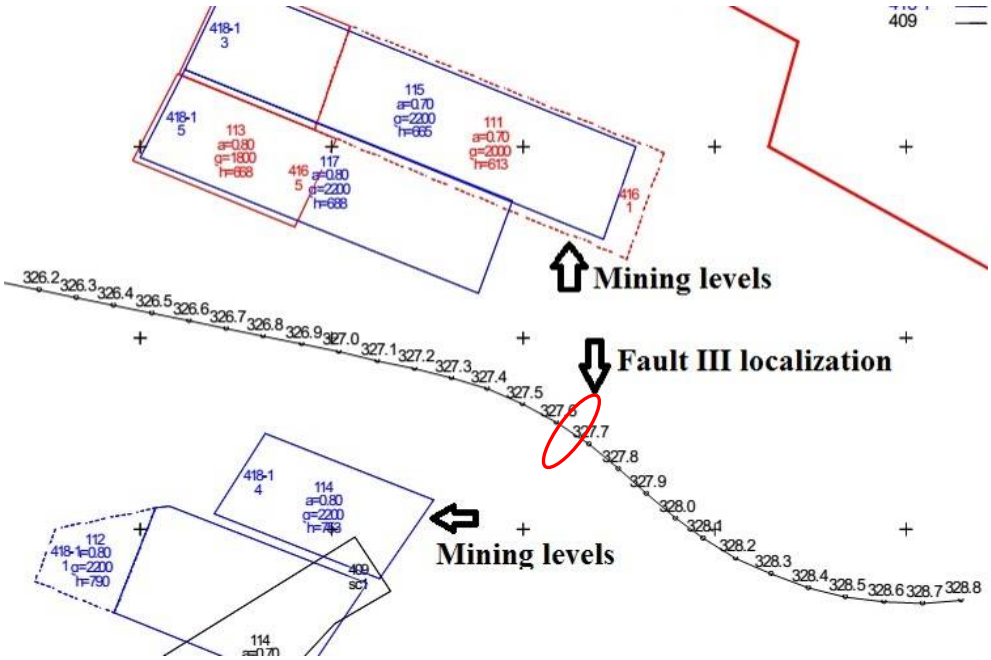


Figure 23. Mining levels predicted to exploited up to 2020.

References

1. The map of the top of the Carboniferous situated along A4 motorway track, belongs to the Mining Authority of "Halemba" Coalmine, scale 1:5000
2. Geological profiles from 1997, 1999 and 2012, scale 1:1000
3. Geological cross sections base on above geological profiles, scale 1:5000
4. The geological surveyor documentation from "Halemba-Wirek" Coalmine
5. The Geotechnical Documentation for A4 motorway from the "Wirek" junction to the "Batory" junction (from 325+232,8 km to 331+470,0 km). Geoprojekt ŚLĄSK Company. 1999
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7. The Geotechnical Documentation „Ocena wpływu powstałych deformacji nieciągłych w rejonie MOP-ów Wirek-Halemba na stan techniczny nawierzchni autostrady A-4 od km 327+300 do km 328+250 oraz kładki dla pieszych KP11 pomiędzy MOP-ami w km 327+500 wraz z przedstawieniem koncepcji rozwiązań naprawczych oraz opracowaniem dokumentacji projektowej umożliwiającej wykonanie robót". Geoprojekt ŚLĄSK Company. Katowice. August 2012.