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PREDICTION OF SUBSIDENCE DEPRESSION DEVELOPMENT

28.1 INTRODUCTION

An extensive network of nearly 100 points was created and repeatedly surveyed to observe the surface manifestations of undermining in the Louky locality near Karvina. The points were surveyed by the GPS method, which enabled the evaluation of changes in the spatial position of each point, i.e. both height (point subsidence) and its horizontal position (point shift). Subsequently, it was possible to model the process of development of the subsidence depression forming above the exploited coal mining panels.

The locality of c. 6 km^2 is situated in the Upper Silesian Coal Basin in the north part of the coal panel in the ČSM Colliery-North, Louky mining area, demarcated by the Darkov Colliery and by the state border of Poland to the east. The location can be characterized as a mining landscape with no residential buildings, with tailings ponds and former mine spoils deposits where vegetation begins to flourish; surface reclamation takes place here. Undermining can cause significant damage to local roads and rail tracks. Four horizontal coal mining panels (see Fig. 1) were gradually exploited here at the depth of c. 1000 meters below the surface in the years 2006-2010. The locality is a part of a wider mining area and other mining activities took place southwards. The rock mass in this part consists of typical for the Upper Silesian Coal Basin upper carboniferous molasse sediments consisting mostly of coal-bearing siliciclastic continental deposits. The Upper Silesian Coal Basin is divided into tectonic blocks by a set of normal faults of tens to hundreds of meters amplitude [4].

Beside the detection of the past and current state and the development trends specifications, the complex evaluation also includes prediction of the state and development in the future. To predict the future subsidence in the study area, an empirical approach was chosen. The following text is based on work of [6]. The evaluation of the measured data, analysis of development of the creating subsidence depression, spatial movements of individual points and additional analysis undertaken within this project can be found e.g. in [1, 2, 3, 5].

28.2 THE ACTUAL STATE OF THE SUBSIDENCE DEPRESSION

Model of the development of the subsidence depression related to the last GPS surveying is presented in Fig. 1. The maximum observed subsidence for the entire period is 165 cm. From the model, the shape of the subsidence depression is evident as well as the interface between the observed subsidence depression and a part of a much larger subsidence depression located in the south.

Mining in the study area was terminated in June 2010. During the next nine months there was a gradual reduction in the subsidence. Area affected only by the extraction of the four monitored longwall panels was in the phase of the subsidence desisting after the last GPS surveying.

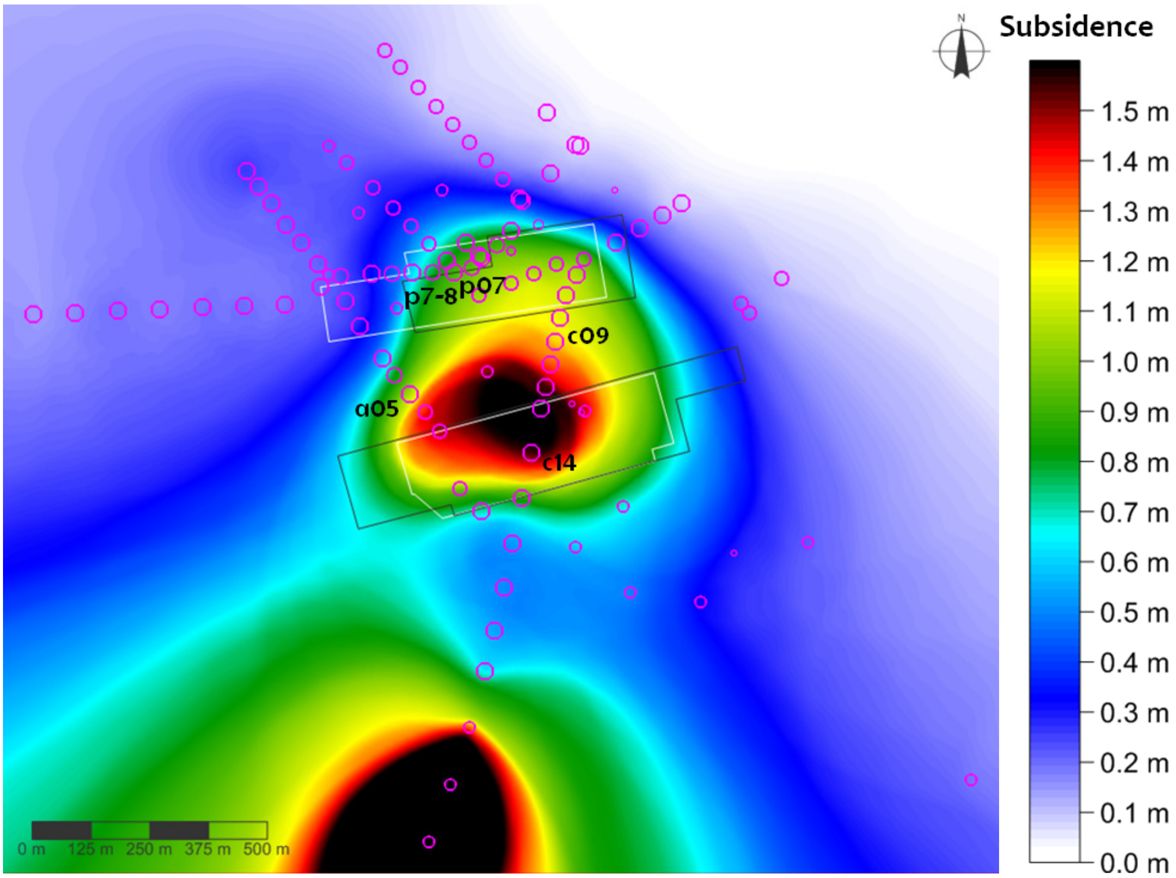

Fig. 28.1 Subsidence depression model for the period November 2006 - March 2011. Size of the GPS point symbols indicates the frequency of their use in creation of sub-grids, whose accumulation resulted in final grid. Only the points mentioned below are identified.

Source: [6]

28.3 THE POSSIBLE FUTURE DEVELOPMENT OF THE SUBSIDENCE DEPRESSION

To determine trends in data series, subsidence curve respectively, regression analysis tools can be used. However, it is always necessary to choose the appropriate regression model, depending on the stage of the subsidence curve development.

In the case of a finite state detected by the GPS surveying, subsidence curves of the points, that were affected only by the exploitation of the monitored mining panels, are in a phase of the subsidence desisting. It is characterized by a gradual reduction of subsidence in the order of millimetres per month. The phase of the subsidence desisting can last several years for deposits of this type. To capture the trend in this phase of development, it is convenient to use a power or exponential regression function.

The predictive calculation was carried out in the MS Excel programming for each of the points separately as follows:

- First we need to determine the inflection point of the subsidence curve showing the development recorded in the last period, i.e. the point (surveying time), when the subsidence per time unit (week) has a maximum value and from this point onwards its value decreases gradually. After its determination, we work only with data ascertained from this surveying (inflection point) onwards.
- For each point in the data series, height difference between the recorded height and the last surveyed height is detected. On the basis of these values, a graph is plotted showing the decreasing rate of the observed subsidence in time.
- Regression curve (power or exponential) is fitted to the plotted points and the index of determination R^2 is set. This function actually does not fit the particular subsidence values but is very close to them. This is reflected in a very low index of determination R^2. Unlike the proposed state that considers the subsidence stabilized in the last surveying, the subsidence is assumed to continue desisting for some time.
- Therefore it is necessary to estimate the degree of the future subsidence, i.e. the total expected subsidence between the last surveying and the stabilization time, while maintaining the trend in the data series. The proposed value of the future subsidence must be added to all of the calculated values of the data series. This process automatically re-draws the graph and re-calculates the regression function. The final value of the total expected subsidence is searched by an iterative manner until the determination index R^2 has the highest degree of tightness.
- Finally, with the resulting regression function, the value is calculated (extrapolated) related to particular date (week), and the subsidence expected for a given period is determined from the difference between this value and the re-calculated value from the last surveying.

In this way, the expected rate of subsidence of the individual GPS points was determined in the period from the last surveying (03/2011) until the supposed renewal of mining activity in the area of interest (01/2012). Example of the final graphical representation is presented in Fig. 2. Such predictive calculation was also applied on a shortened data series, in which no inflection point was included. The results of all variants of calculation (data series with the inflection point and without it, the use of a power or exponential regression function) on selected GPS points are presented in Table 1. Highlighted in bold are the values of the expected subsidence calculated with the use of the best regressive function (highest determination index).

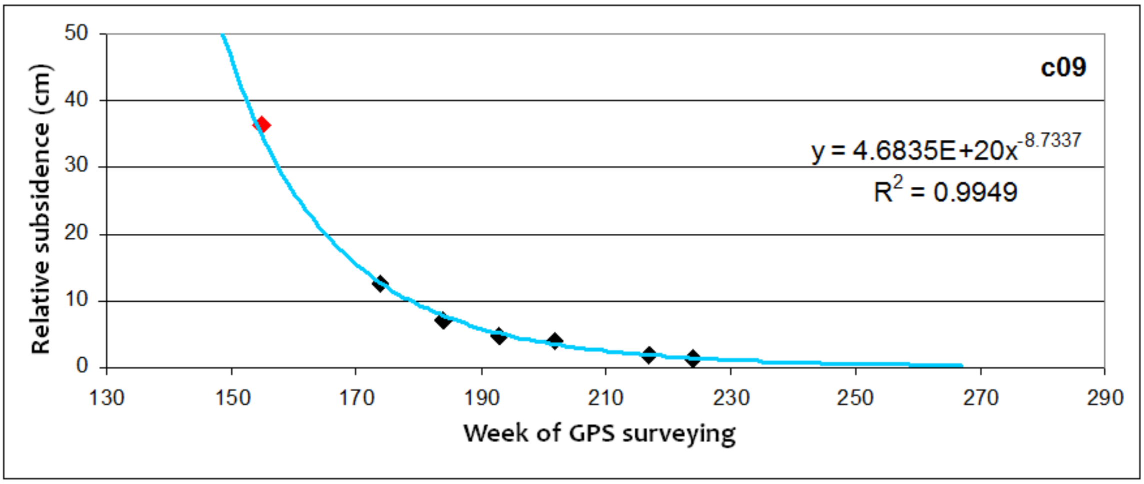

Fig. 28.2 Graphical representation of selected regression function describing the subsidence trend at the sample point c09

Source: [6]

Table 28.1 Prediction of the subsidence in the period 3/2011-1/2012

Point	From the inflection point onwards (including inflection point)				From the inflection point onwards (without inflection point)			
	Power fnc		Exponential fnc		Power fnc		Exponential fnc	
	Subsidence [cm]	R^2 [%]	Subsidence [cm]	R^2 [%]	Subsidence [cm]	R^2 [%]	Subsidence [cm]	R^2 [%]
a05	**-0.95**	**95.56**	-0.73	95.03	-0.79	90.65	-0.64	90.44
c09	**-1.03**	**99.49**	-0.82	99.13	-1.26	99.27	-1.11	99.08
c14	-1.11	99.59	**-0.82**	**99.72**	-0.84	99.68	-0.74	99.50
p7-8	-0.96	98.13	**-0.70**	**98.24**	-1.02	97.12	-0.70	97.39

Source: [6]

From the presented results it is obvious that both the power and exponential regression function exhibited a high degree of tightness to the measured data, and both types are well suited to describe the trend of this subsidence phase. Definitely we can say that better results were achieved in the case of inclusion of the inflection point in the calculation.

For some points the processing was not possible for various reasons, or if so, the achieved results were not too credible. Mainly due to the effects of mining in the surroundings which significantly affected the size of subsidence of some points, also due to very small, usually non-uniform continuous subsidence or some non-standard values of subsidence, especially in the final part of the processed data series.

The latter case was reported e.g. at point p07, see Fig. 3 and Fig. 4 and Table 2. The last point of the data series for unknown reasons (surveying error, local significant subsidence) has much higher subsidence value than was expected according to the development of subsidence curves. Omitting this point of calculation, greater tightness of regression function is achieved. The regression curve shape is also more similar to the curves determined for the surrounding points and the expected value of future subsidence corresponds with the values of expected subsidence at nearby points.

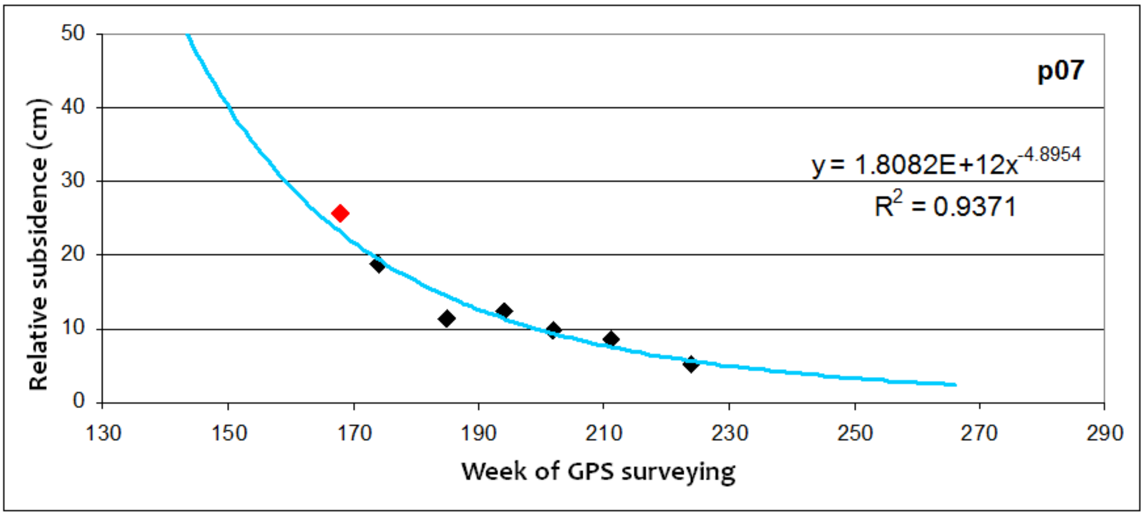

Fig. 28.3 Change of the regression function achieved by the data series correction – the original state

Source: [6]

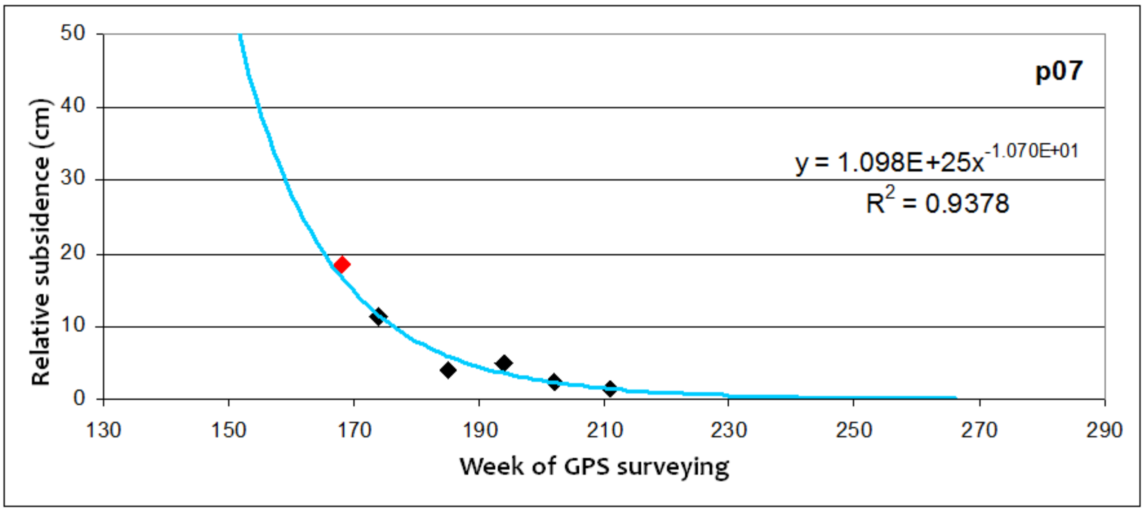

Fig. 28.4 Change of the regression function achieved by the data series correction – state after omitting inconvenient values

Source: [6]

Table 28.2 Correction of subsidence predictions in the period 3/2011-1/2012

Point	From the inflection point onwards (including)				Omitting the last point of surveying			
	Power fnc		Exponential fnc		Power fnc		Exponential fnc	
	Subsidence [cm]	R^2 [%]	Subsidence [cm]	R^2 [%]	Subsidence [cm]	R^2 [%]	Subsidence [cm]	R^2 [%]
p07	-2.79	93.71	-2.69	93.59	**-0.64**	**93.78**	-0.48	93.70

Source: [6]

CONCLUSION

A network of surface points was created and subsequently repeatedly geodetically surveyed to detect surface manifestations of undermining on a selected location near Karvina. Besides evaluating the spatial movements of individual points and modeling of the actual development of the subsidence depression, a procedure has been proposed to predict the future state of the undermined area. This procedure uses the regression analysis tools. The expected subsidence of the points, which could be processed, was about 1 cm for the period since the last measurement (March 2011) until the resumption of mining activities (January 2012). Such value is negligible compared to the total subsidence. The shape and size of the so far captured subsidence depression should not be changed due to this subsidence.

The mining areas in the Upper Silesian Coal Basin are significantly affected by the exploitation. The surface changes markedly not only due to subsidence, but also due to flooded areas and mine spoils deposits on the surface, and the overall re-cultivation that follows the mining activities. Such activities should be planned with respect to the future uses of the undermined areas. Therefore, the knowledge of the future size and duration of the subsidence is needed. The proposed procedure can help to predict the future state of the undermined area and it is essential for planning surface reclamation and other uses of the mining landscape.

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Abstract: *An extensive network of points was repeatedly surveyed by GPS method to monitor the surface manifestations of undermining in the Louky locality near Karvina from 2006 to 2011. The aim was not only to record the development of the creating subsidence depression, its range, size of subsidence and horizontal shifts, but the task was also to predict the future state in the area. Such information is essential for planning surface reclamation and other uses of the undermined areas. Prediction of further development on the basis of GPS data and theoretical knowledge of the subsidence depression development was provided by regression analysis.*

Keywords: *undermining; subsidence; prediction; regression analysis*

PREDIKCE VÝVOJE POKLESOVÉ KOTLINY

Abstrakt: *V letech 2006 až 2011 byla v lokalitě Louky v blízkosti Karviné opakovaně metodou GPS zaměřována rozsáhlá síť bodů s cílem sledovat povrchové projevy poddolování. Vedle zaznamenání vývoje vznikající poklesové kotliny, jejího rozsahu, velikostí poklesů a posunů, bylo naším úkolem stanovit předpokládaný budoucí stav v dané lokalitě. Tyto informace jsou podstatné při plánování rekultivací a dalšího využití poddolovaných oblastí. Predikci dalšího vývoje na základě dat z provedených GPS měření a teoretických znalostí vývoje poklesové kotliny poskytla regresní analýza.*

Klíčová slova: *poddolování, poklesy, predikce, regresní analýza*

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