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POSSIBILITY ANALYSIS OF THE USE OF SMOOTH SPLINE FUNCTIONS TO DETERMINATION THE AVERAGE COURSE OF MINING AREA CURVATURES OBTAINED FROM RESULTS OF GEODESIC MEASUREMENTS

9.1 INTRODUCTION

Running underground exploitation of coalmine causes the occurrence of continuous and discontinuous deformations of area and structures which are seated on it.

The amount of influence of mining exploitation may be expressed, among others, by means of indicators of continuous deformations of mining area, which comprise: subsidences, inclinations, curvatures, horizontal dislocations and horizontal deformations. Real values of these indicators are designated based on the results of surveys run before, during and after termination of exploitation, on points of observation network stabilised in the ground.

Experts in construction on mining areas emphasise [8, 10] that there is a certain group of structures particularly sensitive to area curvatures. They are structures made of monolithic elements, of considerable areas in a horizontal projection and with one dimension dominating over the remaining ones (the so-called linear or oblong objects). It is important that the objects were properly protected against negative effects of underground mining exploitation. It may occur only in case of appropriate designing and placing suitable protections in them, which are selected, among others, depending on the forecasted values of curvatures.

Nowadays it is observable that theoretically calculated extreme values of curvatures are significantly smaller than extreme values of curvatures determined from the results of surveys. A question remains, if it is a fault of an erroneously constructed mathematical model used to make forecasts [2], or a random scattering of measured values, which – among all indicators of curvatures – is the highest for curvatures of mining area [7]. In connection with the forecasted values of curvatures should be compared with their average values measured obtained on the way of approximation of the results of surveys.

Orthogonal polynomials [9] have been mainly used so far to designate an average course of measured values of indicators of mining area deformation (decreases, inclinations and horizontal deformations). The problem with their use depends on determination of an optimal degree of a polynomial within a given indicator of deformation and a need to divide a profile of a subsidence basin into two wings and a bottom.

Due to considerable fluctuations and oscillations of observed values of curvatures [1], the theme of their approximation is not willingly taken up in the source literature. The publications dealing with forms of functions approximating average course of measured curvatures, nor about the possibilities to use a given kind, way or methods of approximation.

With regard to this, methodology of calculating average values of measured curvatures, based on mean square approximation done with the use of smooth splines was demonstrated in this paper. A case of geodetic observations conducted by the employees of a certain coalmine, on an observation line set more or less perpendicularly to the edge of field of exploitation consisting of 4 longwall workings was considered. Average courses of measured curvatures were designated each time after the termination of exploitation of subsequent longwalls. The values of standard deviations between average and measured curvatures σ_C and coefficients of variability of random scattering of M_C curvatures were calculated. Subsequently they were compared with values appearing in literature and based on this the evaluation of the possibility to use smooth splines to designate average course of observed curvatures of mining area was conducted.

9.2 CONDUCTED EXPLOITATION AND SURVEYS

A certain coalmine was running exploitation of a deposit 354 with four longwall workings marked consecutively as 1, 2, 3 and 4. Thickness of a deposit amounted to approx. 1.7 m, and depth of its lying from 270 m to 350 m. The formed post-mining void was filled in with rock rubble deriving from a fall of layers situated over a deposit roof. The overlay was formed by sand, gravel, quaternary clay, silt and Miocene sand of a total thickness amounting to 220 m, as well as Orzesze layers in a form of shale-sandstone facies with a considerable dominance of shales.

For the purpose of monitoring the influence of mining exploitation on a surface area, a measuring line 1A situated perpendicularly to face runs of four longwalls was set. This line consisted of 45 stabilised points in the distances amounting from 20 m to 30 m. The measurements of the height of points (levelling) and the distances among them were run in monthly and bimonthly cycles. It allowed to select such four observation cycles, for which measured subsidences demonstrated the profiles of stative subsidence basins formed after exploiting subsequent longwalls. The situation of an observation line 1A in connection with the edges of exploitation workings in a deposit 354 was demonstrated in the Fig. 9.1.

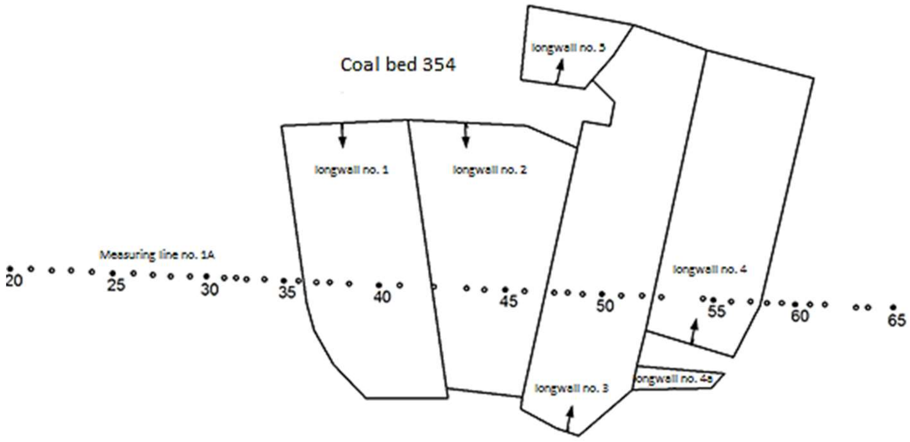

Fig. 9.1 Location of points of measuring line no. 1A in relation to the edges of longwalls no. 1, 2, 3 and 4 in coal bed 354

Source: [3]

9.3 MEASURED AND AVERAGE CURVATURES OF MINING AREA

9.3.1 Methodology of calculating measured and average values of curvatures

Based on subsidences of points (W_i) and length of segments of an observation line ($l_{i,i+1}$) measured in a given cycle, we may calculated real values of curvatures from the following dependence [8]:

$$C_{i-1,i,i+1}^{meas} = \frac{W_{i-1}^{meas} - 2W_i^{meas} + W_{i+1}^{meas}}{l_{aver}^2}, \tag{9.1}$$

where:

$$l_{aver} = \frac{l_{i-1,i}^{meas} + l_{i,i+1}^{meas}}{2};$$

$l_{i-1,i}$, $l_{i,i+1}$ – distances between neighbouring points, which a designation of a curvature was based on;

W_{i-1}, W_i, W_{i+1} – subsidences of three neighbouring points.

The calculated values of curvatures measured after the termination of each of the exploitation stages depict an amount of influence deriving from the exploitation of Longwall 1; Longwalls 1 and 2; Longwalls 1, 2 and 3; Longwalls 1, 2, 3 and 4.

Table 9.1 Parameters values of J. Bialek's formula after termination the next exploitation stages

Exploitation stage	Parameter tgβ	Coefficient of exploitation a	Coefficient of exploitation border A_{obr}	Standard deviation of matching subsidences σ_W [mm]	Coefficient of correlation R
After longwall 1	2.833	0.853	0.167	17.1	0.9992
After longwalls 1+2	2.667	0.902	0.150	16.2	0.9996
After longwalls 1+2+3	2.472	0.956	0.138	27.0	0.9991
After longwalls 1+2+3+4	2.167	0.976	0.117	52.4	0.9967

Source: own study

On the other hand, the average values of measured curvatures were also designated from dependence (1), but based on average values of measured subsidences [4], obtained via mean square approximation conducted by means of smooth splines, with reference to the theoretical values of subsidences calculated by J. Bialek's formula with designated values of his parameters [5, 6]. Table 9.1 presents parameter values of J. Bialek's subsidence formula used to calculate the theoretical subsidence values after the termination of particular exploitation stages.

9.3.2 Calculated values of measured and average curvatures

Fig. 9.2 contains measured (dotted lines) and average (solid lines) courses of curvatures of mining area along an observation line, designated after the termination of consecutive stages of exploitation: after Longwall 1 – black colour, after Longwalls 1 and 2 – blue colour, after Longwalls 1, 2 and 3 – Green colour and after Longwalls 1, 2, 3 and 4 – red colour.

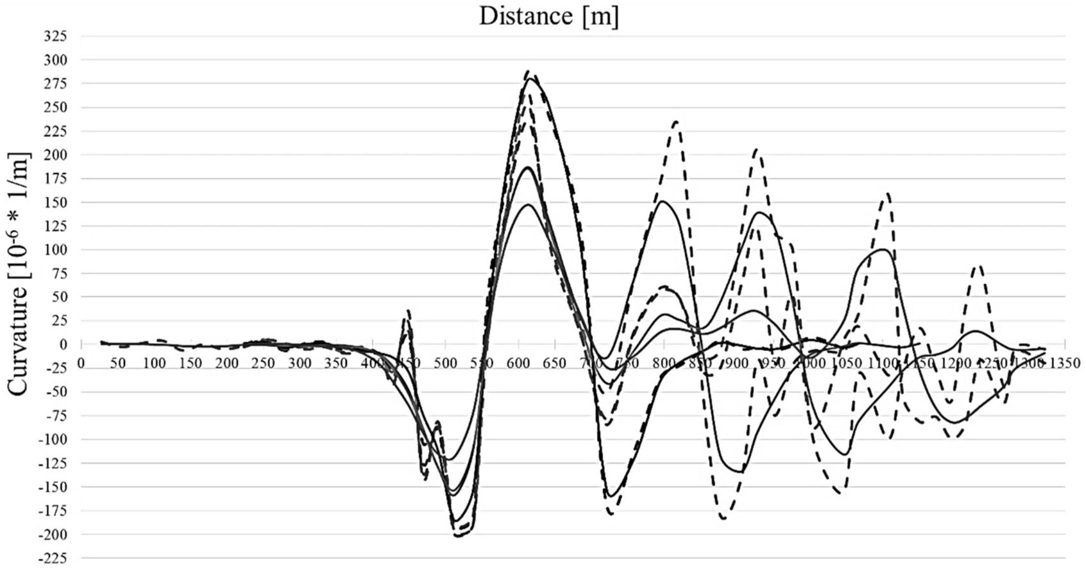

Fig. 9.2 Measured (dotted lines) and average (solid lines) courses of curvatures after termination the next exploitation stages

Source: own study

Table 9.2 presents values of extreme curvatures measured after the termination of consecutive stages of exploitation (C_{extr}^{meas}) and average values ($\mathrm{C}_{\mathrm{extr}}^{\mathrm{aver}}$), corresponding to them, R correlation coefficients between average and observed curvatures, as well as deviations of standard curvatures σ_C and variability coefficients of random scattering from M_C curvatures designated from the dependence (9.2):

$$M_C = \frac{\sigma_C}{|C_{extr}^{aver}|}, \tag{9.2}$$

where:

σ_C – standard deviation between average and measured curvatures;

C_{extr}^{aver} – extreme value of average curvature.

Table 9.2 Measures values of curvatures random dispersion, extreme average and measured curvatures after termination the next exploitation stages

Exploitation stage/Parameter	**After longwall 1**	**After longwalls 1+2**	**After longwalls 1+2+3**	**After longwalls 1+2+3+4**
R	0.9916	0.9460	0.9270	0.8450
σ_C [10^{-6}*1/m]	13.50	36.07	38.21	44.08
M_C [%]	4.84	19.28	20.59	29.91
C_{max}^{meas}[10^{-6}*1/m]	287.40	235.79	267.08	253.16
C_{min}^{meas}[10^{-6}*1/m]	-191.84	-199.47	-196.48	-190.02
C_{max}^{aver}[10^{-6}*1/m]	278.54	187.11	185.56	147.39
Percent of maximal measured curvature [%]	96.92	79.35	69.48	58.22
C_{min}^{aver}[10^{-6}*1/m]	-185.45	-158.58	-153.48	-118.17
Percent of minimal measured curvature [%]	96.67	79.50	78.11	62.19

Source: own study

9.4 DISCUSSION OF RESULTS

The measured courses of curvatures presented by dashed lines in Fig. 9.2 indicate that fluctuations of curvatures increase with increase of scope of exploitation. It is confirmed by data included in Table 9.2, that is decreasing values of R correlation coefficients between measured and average curvatures (from 0.99 after first longwall to 0.85 after four longwalls), as well as increasing values of standard deviation of curvatures σ_C (from 13,5*10^{-6} 1/m after first longwalls to do 44,1*10^{-6} 1/m after four walls) and their variability coefficient of random scattering M_C (from 4.8% after first longwall to 29.9% after four longwalls). The obtained values of coefficient M_C did not exceed values occurring in source literature (Table 9.3); hence we may deduce that smooth splines may be used to designate average values of measured curvatures of mining area. We need to take into consideration the fact that extreme average curvatures are generally smaller from extreme measured curvatures, and the degree of their models decreases with development of exploitation in time.

Table 9.3 Average random scattering of curvatures by various authors

Variability coefficient of curvatures random scattering M_C [%]				
E. Popiołek 1976	**E. Popiołek J. Ostrowski M. Milewski 1999**	**T. Stoch 2005**	**E. Popiołek J. Ostrowski 2005**	**A. Kowalski 2007**
43.0	54.2	47.8	40.0	33.5

Source: [7]

9.5 CONCLUSION

The article demonstrated that there is a possibility to use smooth splines to designate average values of measured curvatures of mining area. Obtaining average courses of observed curvatures allows for their subsequent comparison with theoretical courses calculated with the approved theory of forecasting continuous deformations and the evaluation of their precision and potential specification

REFERENCES

1. A. Kowalski, E. Jędrzejec. „Influence of subsidence fluctuation on the determination of mining area curvatures". *Archives of Mining Sciences*, vol. 60(2), pp. 487-505, 2015.
2. J. Kwiatek. "Górnicze deformacje powierzchni" w *Ochrona obiektów budowlanych na terenach górniczych,* Wyd. Katowice: Główny Instytut Górnictwa, 1998, s. 116. (polish)
3. R. Mielimąka. *Wpływ kolejności i kierunku eksploatacji prowadzonej frontami ścianowymi na deformacje terenu górniczego.* Gliwice, Wyd. Politechniki Śląskiej, 2009, s. 40. (polish)
4. J. Orwat. "Approximation of average course of measured subsidences of mining area by smooth splines" presented at 14th Int. Conf. of Numerical Analysis and Applied Mathematics, Rhodes, Greece, 2016.
5. J. Orwat. "Ocena skuteczności modeli zastosowanych do reprognozy krzywizn terenu górniczego w oparciu o przeciętne przebiegi ich pomierzonych wartości" zaprezentowano na Górnictwie Zrównoważonego Rozwoju, Gliwice, Polska, 2016. (polish)
6. J. Orwat, R. Mielimąka. "Approximation of average course of measured curvatures of mining area with reference to their forecast values by Bialek's formulas" presented at 14th Int. Conf. of Numerical Analysis and Applied Mathematics, Rhodes, Greece, 2016.
7. E. Popiołek. "Wybrane problemy probabilistycznej oceny zagrożenia terenu i obiektów" w *Ochrona terenów górniczych,* Wyd. Kraków: Akademia Górniczo-Hutnicza, 2009, s. 172. (polish)
8. E. Popiołek, M. Milewski, J. Ostrowski. „Próba oceny przydatności krzywizny profilu niecki obniżeniowej jako wskaźnika zagrożenia obiektu poddawanego wpływom podziemnej eksploatacji górniczej (na przykładzie LGOM)". *Przegląd Górniczy*, t. 51, nr 11(866), s. 1-7, listopad 1995. (polish)
9. T. Stoch, Z. Niedojadło, P. Sopata, S. Moskała. „Funkcje aproksymujące przeciętny przebieg wskaźników deformacji dla wyznaczenia parametrów rozproszenia losowego pogórniczych przemieszczeń i deformacji powierzchni terenu". *Przegląd Górniczy*, t. 70, nr 8(1101), s. 113-123, sierpień 2014. (polish)
10. K. Trojanowski. "Teoretyczne przesłanki badań krzywizny terenu" w *Prace Komisji Górniczo – Geodezyjnej, Geodezja 4,* Wyd. Kraków: Polska Akademia Nauk, 1968, s. 31-62. (polish)

Date of submission of the article to the Editor: 04.2017
Date of acceptance of the article by the Editor: 05.2017

MSc Eng. Justyna Orwat
Silesian University of Technology
Faculty of Mining and Geology
ul. Akademicka 2A, 44-100 Gliwice, Poland
tel.: +4832 237 29 96, e-mail: Justyna.Orwat@polsl.pl

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Abstract: *In this paper was done an analysis of possibility of the use of smooth spline functions to obtaining of an average course of mining area curvatures. Their values were calculated on the basis of geodesic observations results, were conducted into the boundaries of some mining area. The analysis was done based on the counting of standard deviations between the empirical and mean values of curvatures (σ_C) and variability indicators of curvatures' random dispersion (M_C). They were compared with the pattern values occurring in the professional literature.*

Key words: *a random scattering (fluctuation) of the mining area curvatures, an approximation, a smooth spline.*

ANALIZA MOŻLIWOŚCI ZASTOSOWANIA WYGŁADZONYCH FUNKCJI SKLEJANYCH DO WYZNACZENIA PRZECIĘTNEGO PRZEBIEGU KRZYWIZN TERENU GÓRNICZEGO OTRZYMANYCH Z WYNIKÓW POMIARÓW GEODEZYJNYCH

Streszczenie: *W pracy dokonano analizy możliwości wykorzystania wygładzonych funkcji sklejanych do wyznaczenia przeciętnego przebiegu krzywizn terenu górniczego, których wartości obliczono na bazie wyników obserwacji geodezyjnych prowadzonych w granicach pewnego obszaru górniczego. Niniejszą analizę przeprowadzono w oparciu o obliczenie odchyleń standardowych pomiędzy empirycznymi a średnimi wartościami krzywizn (σ_K) oraz wskaźników zmienności rozproszenia losowego krzywizn (M_K) i porównanie ich wartości z wzorcowymi, pojawiającymi się w literaturze przedmiotu.*

Słowa kluczowe: *rozproszenie losowe (fluktuacja) krzywizn terenu górniczego, aproksymacja, splajn wygładzony*