Arch. Min. Sci. **65** (2020), 3, 641-664

Electronic version (in color) of this paper is available: http://mining.archives.pl

DOI 10.24425/ams.2020.134139

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INFLUENCE OF ROCK GEOMECHANICAL PARAMETERS ON INCREASED LONGWALL ABSOLUTE METHANE EMISSION RATE FORECASTING ACCURACY

In longwall absolute methane emission rate forecasting, the range of the destressing zone is determined empirically and is not considered to be dependent on the geomechanical parameters of the rock strata. This simplification regarding destressing zone determination may result in significant differences between the forecast and the actual methane emission rates. During the extraction of coal seams using a system involving longwalls with caving under the conditions of low rock mass geomechanical parameters, the absolute methane emission rate forecasts are typically underestimated in comparison to the actual methane emission rates.

In order to examine the influence of the destressing zones on the final forecasting result and to assess the influence of the rock mass geomechanical parameters on the increased accuracy of forecast values, destressing zones were determined for three longwalls with lengths ranging from 186 to 250 m, based on numerical modelling using the finite difference method (FDM). The modelling results confirmed the assumptions concerning the upper destressing zone range adopted for absolute methane emission rate forecasting. As for the remaining parameters, the destressing zones yielded great differences, particularly for floor strata. To inspect the accuracy of the FDM calculation result, an absolute methane emission rate forecasting algorithm was supplemented with the obtained zones. The prepared forecasts, both for longwall methane emission rates as well as the inflow of methane to the longwalls from strata within the destressing zone, were verified via underground methane emission tests. A comparative analysis found that including geomechanical parameters in methane emission rate forecasting can significantly reduce the errors in forecast values.

Keywords: methane hazard, methane emission rate forecasting, FDM simulations, numerical modeling, destressing (desorption) zone

1. Introduction

Absolute methane emission rate forecasting methods are used in order to predict the methane hazards present in longwall extraction areas. Their results, at the stage of extraction planning, play

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a key role from the perspective of preliminary methane hazard assessment, selection of preventive measures, and particularly for the methane drainage method employed. Consequently, the forecasting accuracy has an influence on the practical implementation of the adopted guidelines concerning extraction levels and the safety of mining plant operations.

Comparative analyses of forecast values in relation to actual values occasionally 50% can be exceeded, even though the assessments adopt many interpolated parameters that are not obtained as a result of direct tests. Such a situation occurs most often when there is no data concerning the methane content for over half the coal seams present in a given stratigraphic column. Unpredictable factors are often present as well and these are related to the occurrence of geological disturbances (faults) that result in local increases in longwall methane emission rates (Cheng et al., 2019a, 2019b).

Employed longwall absolute methane emission rate forecasting methods typically assume a direct relationship between the longwall advance and the rate of methane emissions to the longwall environment, or an indirect relationship regarding the daily extraction output. This results from the assumption that the moving longwall face leads to the generation of a destressing zone, the volume of which increases proportionally to the rate of face advance. As a consequence of multi-level coal seam mining, which is a characteristic of the Upper Silesian Coal Basin, and the deposition of numerous methane-rich coal seams in the destressing zone, the contribution of methane inflow to the longwalls from coal seams within the destressing zone is high and varies within the range of 70 to 80% (Wierzbiński, 2016). It can therefore be assumed that the rate of methane inflow to the longwall environments from coal seams within the destressing zone has key significance for forecasting the absolute methane emission rate (Koptoń, 2015; Krause, 2009).

In the case of longwall absolute methane emission rate forecasting employed in Polish hard coal mining (GIG Instruction, 2000), the range of the destressing zone is determined empirically and is not considered to depend on the geomechanical parameters of the rock strata. This simplification regarding destressing zone determination may result in significant differences between the forecast and the actual methane emission rates.

In order to determine the influence of the destressing zones on the final forecasting result and to assess the influence of the rock mass geomechanical parameters on the increased accuracy of the forecast values, absolute methane emission rate forecasts were provided in the article, with both the inclusion and the omission of rock mass geomechanical parameters. The forecasting result accuracy levels were verified on the basis of tests of actual methane emissions from the analysed longwall environments.

2. Research subject characteristics, reasons for the longwall selection

The research scope encompassed three longwalls with caving, developed under the conditions of a high methane hazard. The criteria for selecting these subjects included:

- high total absolute methane emission rate (over 20 m^3CH_4/min),
- the conduction of methane drainage,
- the distance of the longwall face from the extraction commencement location (at least 200 m),
- low geomechanical parameters of the rock strata, significantly different from the average values for the Upper Silesian Coal Basin.

The criterion of the total absolute methane emission rate of over 20 m^3CH_4/min made it possible to prepare a precise ventilation-and-methane balance, used, in particular, to determine the components of the total longwall methane emission rate, i.e. the methane emission rate from the mined coal seam and the methane emission rates from adjacent strata within the destressing zone. The condition of the distance of the longwall face from the extraction commencement location (>200 m) guaranteed a stable range of the destressing zone and excluded the possibility of no zone range expansion during the movement of the longwall face.

The mining parameters of these longwalls, together with total relative methane emission rates and methane capture to the drainage network, are presented in Table 1 (Fig. 1). Tables 2-3 present parameter compilations concerning the deposition of roof and floor coal seams as well as their gas properties (methane content).

TABLE 1

Studied longwall parameters

Subject Longwall (seam)	**Length**	**Height**	**Longwall face distance**	**Target panel length**	**Average output**	**Methane emitted to longwall, Qwe**	**Methane drainage, Qo**	**Total methane emission rate, Qc**
	m	m	m	m	Mg/d	m^3CH_4/min	m^3CH_4/min	m^3CH_4/min
A-2 (63+62/3)	186	2.95	220	785	3178	19.52	12.35	**31.87**
B-2 (62/1)	250	1.90	265	605	1391	23.01	9.07	**20.59**
E-4 (04/1)	206	1.80	330	550	3105	12.96	8.93	**21.80**

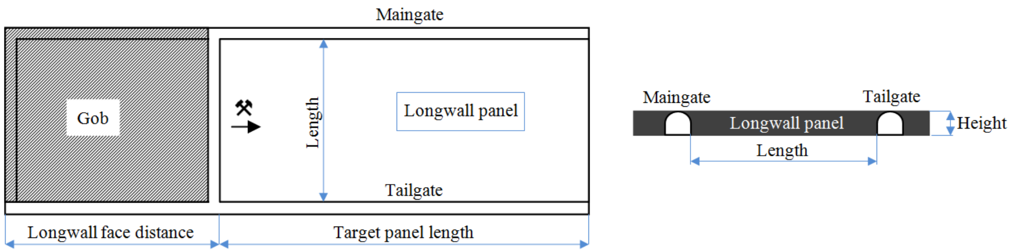

Fig. 1. Longwall panel layout

TABLE 2

Roof conditions for methane-bearing strata

No.	**Parameter**	**Longwall A-2, coal seam 63+62/3 (up to 135 m)**	**Longwall B-2, coal seam 62/1 (up to 130 m)**	**Longwall E-4, coal seam 04/1 (up to 140 m)**
1	**2**	**3**	**4**	**5**
1	Number of coal strata	9	10	11
2	Number of sandstone strata	1	1	0

1	2	3	4	5
3	Number of studied coal strata	3	2	5
4	Average coal stratum thickness, m	1.47	1.06	1.18
5	Distance from the mined coal seam, m	15.3-123.8	25.5-116.4	6.5-139.2
6	Coal stratum methane content range, m^3CH_4/Mg_{csw}	0.00-5.06	0.00-6.96	0.00-4.48
7	Average coal stratum methane content, m^3CH_4/Mg_{csw}	2.94	4.29	1.86

TABLE 3

Floor conditions for methane-bearing strata

No.	Parameter	Longwall A-2, coal seam 63 + 62/3 (up to 75 m)	Longwall B-2, coal seam 62/1 (up to 100 m)	Longwall E-4, coal seam 04/1 (up to 60 m)
1	Number of coal strata	6	7	5
2	Number of sandstone strata	1	2	0
3	Number of studied coal strata	2	2	2
4	Average coal stratum thickness, m	1.09	1.54	1.28
5	Distance from the mined coal seam, m	0.0-70.5	9.0-95.5	5.1-58.8
6	Coal stratum methane content range, m^3CH_4/Mg_{csw}	5.96-10.20	7.30-10.20	6.34-12.10
7	Average coal stratum methane content, m^3CH_4/Mg_{csw}	9.24	9.76	10.19

3. Applied research methodology

The primary goal of the applied research methodology was to determine:

- the differences between the vertical ranges of destressing zones (including the coal seam degasification zones in the longwall environment), which were determined using the empirical method according to GIG Instruction no. 14, and using FDM modelling for the additional consideration of rock stratum geomechanical parameters,
- the influence of the addition of destressing zones (defined based on FDM modelling) to a forecasting algorithm on errors in longwall methane emission rate forecasts and in methane emission forecasts from coal seams in the destressing zone.

To accomplish the established goals, the scope of the research methodology encompassed:

I. Determining the vertical destressing zone range, including the number of present methane-bearing coal seams and the individual volumes of their degasification zones (with reference to a single coal seam) – based on two methods:
   - the empirical method according to GIG Instruction No. 14,
   - FDM numerical modelling using the FLAC2D software,

II. Forecasting an absolute methane emission rate, including a methane emission forecast from the coal seams present in the destressing zones, based on:
   - empirical method calculation results according to GIG Instruction No. 14,
   - FDM numerical calculation results,

III. Conducting measurements of actual absolute methane emission rates and methane emissions from strata adjacent to the longwall environments, in order to verify the accuracy of forecast values and to assess the possibility of utilising FDM to forecast methane emissions.

3.1. The empirical destressing zone range determination method according to GIG Instruction no. 14

In Polish hard coal mining, the absolute methane emission rate forecasting method employed is based on an algorithm defined in GIG Instruction no. 14, titled "Dynamic longwall absolute methane emission rate forecasting" (GIG Instruction, 2000). This method utilises empirical relationships that make it possible to define the degasification range for rock strata deposited below and above a longwall working as a result of the mining conducted, regardless of their geomechanical parameters. An upper desorption zone range (h_g) is determined for rock strata deposited above the longwall working, which are known as overlaying strata, while for underhand strata it is the lower desorption zone range (h_d).

According to the empirical method, the ranges of the upper and lower destressing zones (desorption zones) depend on the longwall length (Ls) and the transverse longwall inclination (a). The ranges are defined using formulas (1) and (2):

– for overlaying coal seams:

$$h_g = \frac{Ls}{G_g}, \ \text{m} \tag{1}$$

– for underlaying coal seams:

$$h_d = \frac{Ls}{G_d}, \ \text{m} \tag{2}$$

where: G_g, G_d are factors depending on the transverse longwall inclination. The width of the degasification zone for a coal seam within the destressing zone range (X_g, X_d) is determined using formulas (3) and (4):

– for an overlaying coal seam:

$$X_g = Ls - G_g \cdot a, \ \text{m} \tag{3}$$

– for an underlaying coal seam:

$$X_d = Ls - G_d \cdot b, \ \text{m} \tag{4}$$

where a and b are the distance of the overlaying (or underlaying) coal seam from the mined coal seam.

3.2. Destressing zone range determination method based on FDM numerical modelling

3.2.1. Calculation method selection

The FLAC2D software was used for the numerical calculations of the floor and roof stratum degasification zone range in the area of the developed longwalls with caving (Chinkulkijniwat et al., 2015; Karacan et al., 2005; Prassetyo & Gutierrez, 2014; Rajwa et al., 2020; Rajwa et al., 2019). The program operates based on the finite difference method (FDM). A characteristic feature of the employed calculation method is that all the derivatives in a given system of equations described by algebraic expressions are stored in discrete points in the form of a set of variable stresses or deformations. However, the variables are not defined within the element area.

The finite element method (FEM) requires the stress or displacement values to vary in each element, depending on the functions that describe them. Utilising both the FDM and FEM methods requires solving a system of algebraic equations. Although the ways of formulating the systems of equations differ significantly for the two methods, the systems themselves are the same for both of them. However, FEM programs build a global stiffness matrix from individual element stiffness matrices as a matter of convention, whereas FDM programs change the system of differential equations after performing each calculation step, which seems to be a more efficient method. The program uses an explicit method of consecutive steps to solve the system of differential equations. On the other hand, most FEM programs use an implicit method of global stiffness matrix building. FDM makes it possible to build a system of differential equations for any element shape. This is the procedure that is utilised in the FLAC2D program. It solves every static problem using dynamic equations of motion. One of the reasons for using such a method is the necessity to ensure numerical system stability when the modelled physical system is unstable. In the case of materials with non-linear strength and deformability characteristic, a loss of physical balance is always possible (e.g. through sudden pillar failure). A certain amount of deformation energy is then transformed into kinetic energy, which subsequently undergoes dissipation. To put it simply, the calculation cycle is as follows (Itasca, 2008):

- building equations of motion based on velocity and displacement values obtained from stress and force values,
- deformation increments are calculated based on velocity and afterwards they are used to calculate the stresses.

The program performs consecutive calculation cycles at each time step. The most important advantage of this calculation method is the ability to bypass the need to iterate stresses from deformations within each element. Typically, FEM software uses an implicit calculation method. In this method, each element "communicates" with all the other elements during the consecutive steps of the solution. Thus, to obtain a state of equilibrium, it is necessary to perform an entire series of iterations.

3.2.2. Assumptions for destressing range modelling

Considering that the analysed longwall extraction encompassed longwalls developed under various geological and mining conditions, i.e. in three different coal seams with roof caving, the numerical destressing range calculations required the adoption of individual and independent assumptions for these subjects. The analysed situation concerns opened and mined coal seams in one of the mines in the Upper Silesian Coal Basin:

- longwall B-2, coal seam 62/1,
- longwall A-2, coal seam 62/3+63,
- longwall E-4, coal seam 04/1.

Fig. 2 presents an example of a fragment of roof and floor rock stratigraphic column in the environments of the aforementioned coal seams that constituted the basis for building the rock mass numerical models in the area of the conducted mining activities. It can be observed in the presented column that the analysed coal seams are primarily deposited adjacent to clay shale strata and partially adjacent to sandstone strata.

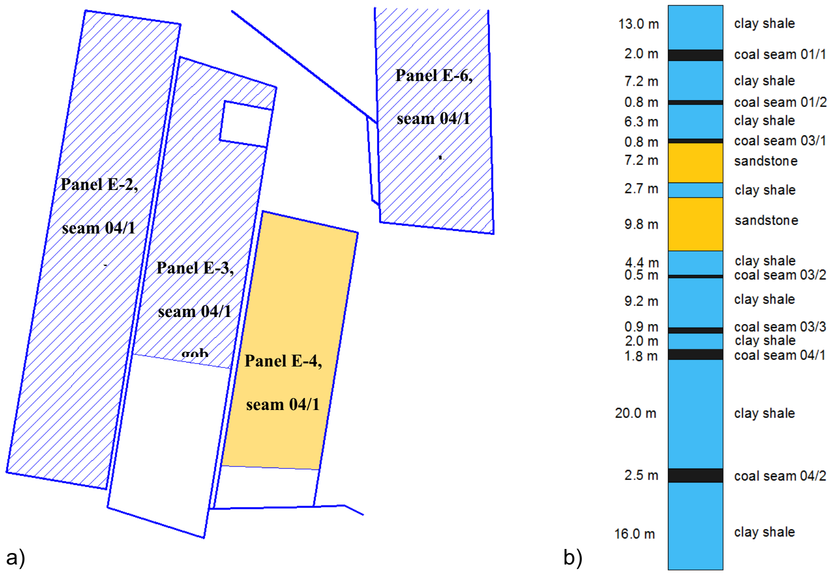

Fig. 2. Diagram of longwall E-2, E-3 and E-4 locations in coal seam 04/1 (a); and fragment of a rock stratigraphic column in the area of the conducted extraction (b)

Based on the longwall diagrams and stratigraphic columns, rock mass numerical models were generated in FLAC2D for the three analysed longwall extractions. The models were built in the form of discs with the following dimensions (width × height):

- 1050 × 350 m for longwalls in coal seam 62/1,
- 420 × 330 m for longwalls in coal seam 62/3+63,
- 1050 × 400 m for longwalls in coal seam 04/1 (Fig. 3).

The sizes of these models, particularly their widths, depended primarily on the number of extracted longwalls in a given coal seam. The models encompassed two longwalls, each 250 m width, for coal seam 62/1, one 186 m width longwall for coal seam 62/3+63, and three longwalls, each 206 m width, for coal seam 04/1. In the individual coal seams, these longwalls were mined for heights of, respectively, 3.4 m, 4.2 m and 1.8 m.

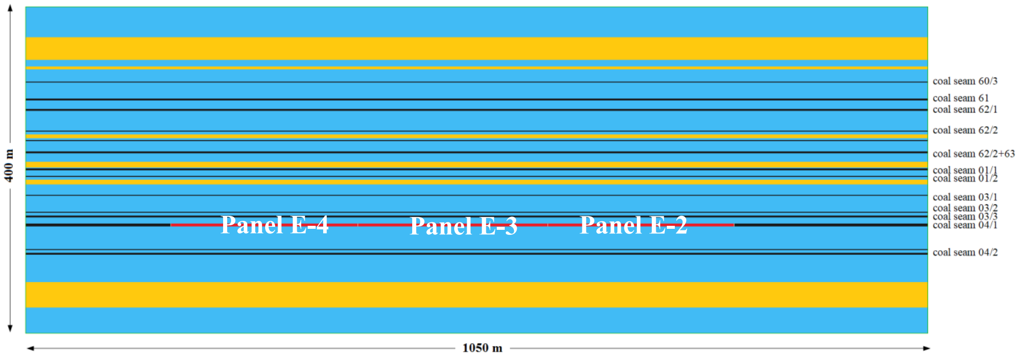

Fig. 3. Numerical model of the rock mass surrounding the mined longwall E-4, coal seam 04/1

A significant element of each numerical model, apart from generating geometry reflecting the geological and mining conditions, is the appropriate selection of the physicomechanical parameters of the individual rock strata and the implementation of an appropriate failure condition. For the purposes of the destressing zone range analysis, the numerical calculations were conducted using the Coulomb-Mohr elasto-plastic model. The Coulomb-Mohr model made it possible to factor in rock mass plasticity, i.e. the non-linearity of rock mass stress and deformability characteristics. Including the rock mass plasticity generally consisted in assuming that the rock mass behaves in a linear elastic manner in areas limited by certain surfaces and in a plastic manner outside these areas. In the program, the plasticity is based on the assumption that the total deformation increment is split into elastic and plastic deformation increments.

In the numerical procedure, a deformation increment resulting from the application of Hooke's law is calculated first, and afterwards stresses are calculated based on the deformation values. If the obtained stress values are outside the boundary surface (defining the adopted strength criterion), then the occurrence of plastic deformations is assumed. In this case, only elastic deformations are included in the procedure of further stress increment calculations (Itasca, 2008).

The basic rock stratum parameter values adopted for the calculations, including those describing the Coulomb-Mohr failure condition, are compiled in Table 5. The parameters were defined on the basis of penetrometric rock tests conducted in the area of the analysed longwalls.

TABLE 5

Basic rock mechanical parameters in the area of the analysed longwalls adopted for numerical calculations

Rock type	**Young's modulus *E*, GPa**	**Poisson's ratio υ**	**Tensile strength R_r, MPa**	**Cohesion *c*, MPa**	**Angle of internal friction φ^o**
coal	2.5	0.25	0.039	0.54	24
clay shale	4.5	0.25	0.074	0.75	27
sandstone	10.5	0.25	0.240	1.90	33

Furthermore, the following assumptions were adopted for the presented models:
- no vertical displacements at the horizontal edges of the model disc,
- no horizontal displacements at the vertical edges of the model disc,
- the modelled rock mass is an elasto-plastic and isotropic medium,

– the geostatic stresses are a result of the extracted longwall depths and the average weight by volume of the overlay:
  - 22.5 MPa for longwall B-2 in coal seam 62/1,
  - 24.1 MPa for longwall A-2 in coal seam 62/3+63,
  - 21.2 MPa for longwall E-4 in coal seam 04/1.
– after obtaining the initial stress state, the displacement and velocity vectors were reset,
– in the next step, a null model was assigned to zones corresponding to the longwall panel and the model was recalculated.

For the presented and adopted numerical model boundary conditions, calculations were conducted for the destressing zone range (rock mass fracturing zone) surrounding the mined longwalls with caving, which consequently provided the basis to determine the rock mass degasification range.

3.3. Longwall absolute methane emission rate forecasting algorithm based on empirical calculation and FDM modelling results

The employed longwall absolute methane emission rate forecasting algorithm, based on FDM calculation results, does not generally diverge from the main principles that were adopted for the utilised empirical method according to GIG Instruction no. 14. Similarly, it is assumed that the forecast methane emission rate in a longwall (Q_{prog}) constitutes a sum of:
– the methane inflow from the mined coal and the longwall face, Q_{EKSP}
– the methane inflow from coal seams (overlaying and underlaying strata), Q_{des}
– the methane inflow from gobs, Q_z

$$Q_{prog} = Q_{EKSP} + Q_{des} + Q_z \tag{5}$$

For both forecasts, it was assumed in the calculations that the methane emissions from the mined coal seam (Q_{EKSP}) to the longwall are consistent with the following relationship (6):

$$Q_{EKSP} = c \cdot \frac{Ls \cdot m_e \cdot \gamma \cdot z \cdot W_e \cdot \varphi_e}{100 \cdot t}, \quad \text{m}^3\text{CH}_4/\text{min} \tag{6}$$

It was, furthermore, assumed that the inflow of the desorbed methane to the longwall environment from roof and floor strata within the destressing zone (Q_{des}) can be described with the following relationship (7):

$$Q_{des} = \frac{c \cdot p}{1.44 \cdot 10^{-5}} \cdot \left[\begin{array}{l} \sum_{i=1}^{n} \left(\gamma_{gi} \cdot m_{gi} \cdot X_{gi} \cdot W_{gi} \cdot \varphi_{gi} \right) + \\ + \sum_{i=1}^{m} \left(\gamma_{di} \cdot m_{di} \cdot X_{di} \cdot W_{di} \cdot \varphi_{di} \right) \end{array} \right], \quad \text{m}^3\text{CH}_4/\text{min} \tag{7}$$

As per GIG Instruction no. 14, for the forecasting algorithms, the inflow of methane from gobs (Q_z) constitutes 20% of the sum of the following components Q_{EKSP}, Q_{des} was adopted. Table 6 presents an explanation of the symbols used in formulas (6) and (7).

TABLE 6

Explanation of the symbols used in formulas (6) and (7)

No.	Symbol	Explanation	Formula
1	c	correction factor, -	$c = 1.24\,p^{-0.32}$
2	m_e	longwall height, m	
3	g	coal density, Mg/m^3	
4	z	coal deposition depth, m	
5	W_e	mined coal seam methane content, m^3CH_4/Mg_{csw},	
6	t	mining cycle duration, minutes	
7	f_e	mined coal seam degasification level, %	$f_e = 18.355 \cdot W_e^{0.5404}$ $f_e = 8.354 \cdot W_e^{0.67}$
8	p	daily longwall face advance, m/d	
9	n	number of underlaying strata (coal seams), -	
10	m	number of overlaying strata (coal seams), -	
11	$W_{gi}(W_{di})$	remaining i-th overlaying (underlaying) stratum methane content, m^3CH_4/Mg_{csw},	
12	g_{gi} (g_{di})	density of coal or of the methane-bearing sandstone stratum constituting the i-th overlaying (underlaying) stratum, Mg/m^3	
13	$m_{gi}(m_{di})$	i-th overlaying (underlaying) stratum thickness, m	
14	f_{gi}	i-th overlaying stratum degasification level, %	$\varphi_{gi} = 67.71 \cdot e^{-0.04\,lu(gi)}$
15	f_{di}	i-th underlaying stratum degasification level, %	$\varphi_{di} = 54.14 \cdot e^{-0.037\,lu(di)}$
16	$lu_{(gi)}$ $lu_{(di)}$	adopted distance of the i-th overlaying/underlaying stratum from the mined coal seam, m	$lu = l/m_e \cdot a$
17	l	actual vertical distance of the overlaying/underlaying stratum from the mined coal seam, m	
18	a	roof control method-dependent factor, -	$a = 1$, for caving,

A significant difference in the forecasting algorithm relates to the definition of parameters X_{gi} and X_{di} in relationship (7) regarding the methane inflow to the longwall environment from adjacent strata within the destressing zone. These parameters concern, respectively:

- X_{gi} – i-th overlaying stratum degasification zone width within the range of the destressing zone, m,
- $\boldsymbol{X_{di}}$ – i-th underlaying stratum degasification zone width within the range of the destressing zone, m.

The X_{gi} and X_{di} parameters will be adopted depending on the utilised longwall absolute methane emission rate forecasting method, i.e.:

- for methane emission rate forecasting using the empirical method, i.e. according to GIG Instruction no. 14, the X_{gi} and X_{di} values will be calculated using formulas (3) and (4),
- for methane emission rate forecasting with destressing zone implementation, the X_{gi} and X_{di} values will be determined based on the results of numerical modelling (FDM) in FLAC2D.

Regardless of the adopted algorithm, it was necessary to adopt initial methane content based on value interpolations from the methane content gradient for approximately 55-80% of the coal seams in the forecasts, due to the lack of direct tests regarding the methane content in these coal seams. Methane content within the range of 0.5 to 1.5 m^3CH_4/Mg was adopted for sandstones with thickness greater than 5 m and deposited adjacent to coal seams with methane content greater than 8 m^3CH_4/Mg_{scw}. The forecasts also included the influence of earlier extractions on the decrease in initial rock mass methane content within the range of the destressing zones.

3.4. Applied underground test methodology for methane emissions in the longwall environments

Methane emission balancing in the analysed longwall areas was conducted based on underground tests of air distribution and methane concentrations in the workings as well as on data from reports on methane capture to the drainage network.

As part of the underground tests determining air flow rates in the workings, geometric measurements of the longwall workings and roadways were conducted, as were air velocity measurements. The working geometric parameter measurements, i.e. width and height, were performed using a measuring tape with accuracy of up to 5 cm, with reference to the working lining. The air velocity measurements were taken throughout the cross-sectional area, based on two independent methods (traverse measurement and averages taken from point measurements). The air velocity point measurements in the gallery workings (component parallel to the working axis) were conducted according to a measuring grid with a side length of 0.5 m (Wierzbiński, 2016). The velocity measurements utilised mAS-4 vane anemometers (IMG PAN) with a reduced measuring range (<0.2 m/s). The methane concentration measurements utilised personal X-am 5000 gas detectors and air testing by the pipette method for chromatographic laboratory analysis. 14 measurement series were performed as part of the testing.

The measuring point distribution is presented in the example of the Longwall E-4 ventilation diagram (Fig. 4). The measuring point distribution was adopted in order to determine such ventilation parameters as:

- methane emitted to the longwall environment,
- total absolute methane emission rate in the environment,
- methane flow to the longwall environment with the fresh air current,
- methane emissions to the longwall environment from the overlaying and underlaying deposits.

The calculations were performed based on relationships (8)-(12), where the subscripts in the formulas refer to the measuring location ID (according to the diagram in Fig. 4). The following daily methane emission indices were calculated for the longwalls:

Methane flow to the longwall environment with the fresh air current – methane inflow from additional sources, primarily gobs and driven workings:

$$Q(dod) = (Q_1 \times n_1) \times 0.01, \quad m^3/min \tag{8}$$

where:
n_1 – average methane concentration in the longwall cross-section (longwall face end), %
Q_1 – average air flow rate measured in the longwall, m^3/min

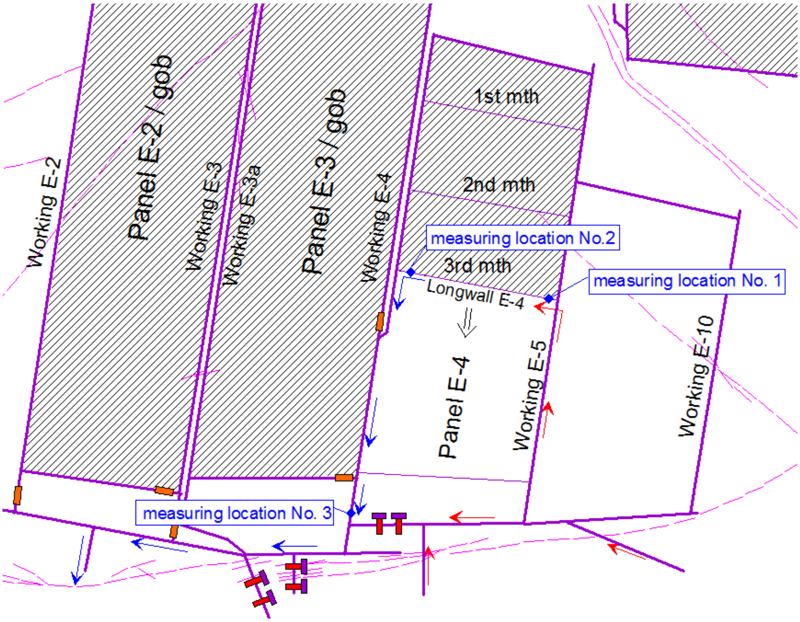

Fig. 4. Longwall E-4, coal seam 04/1 area ventilation diagram with ventilation measurement locations

<u>Methane emitted to the longwall environment:</u>

$$Qwe(rej) = [(Q_3 \times n_3) - (Q_1 \times n_1)] \times 0.01, \;\; \text{m}^3/\text{min} \tag{9}$$

where:
n_3 – average methane concentration in the gallery working, %
Q_3 – average air flow rate measured in the gallery working, m^3/min

<u>Methane emitted to the longwall:</u>

$$Qwe(sc) = [(Q_1 \times n_2) - (Q_1 \times n_1)] \times 0.01, \;\; \text{m}^3/\text{min} \tag{10}$$

where:
n_2 – average methane concentration in the longwall at the face end, %

<u>Total absolute methane emission rate in the environment:</u>

$$Qc(rej) = Qwe(rej) + Qo \tag{11}$$

<u>Methane emissions from the overlaying and underlaying deposits to</u> the longwall environment:

$$Q(des) = Qwe(rej) - Qwe(sc) + Qo \tag{12}$$

4. FDM numerical calculation results for the destressing zone range

The numerical calculation results for the two of three analysed longwalls are presented in the form of rock stratum plasticity index plots (Fig. 5-6). These indices are displayed over a vertical section (transverse to the panel) and illustrate the range of the rock fracturing zone around the conducted longwall extraction. Boundary lines which separate the destressing zones (trapezoid shape) from the remaining part of the undamaged rock mass were also marked in these figures and the vertical distribution of the rock mass degasification level was fitted to the obtained zones,

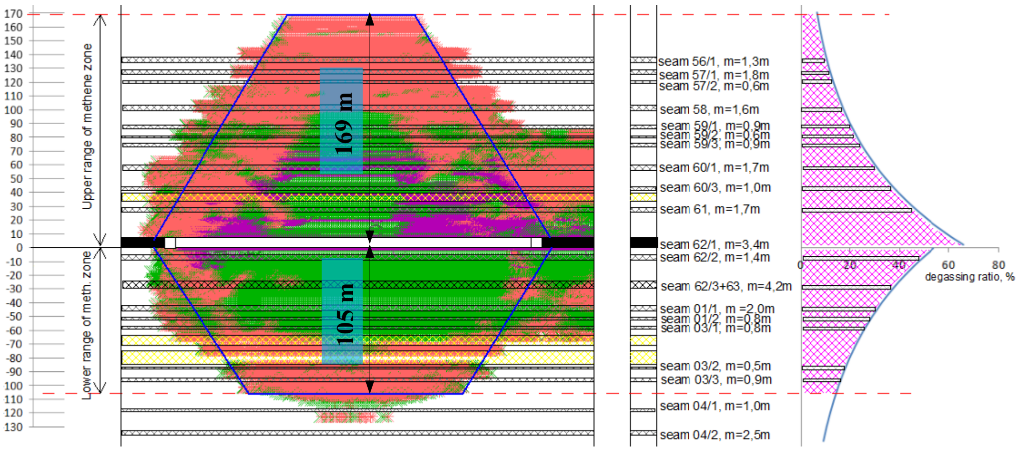

Fig. 5. Destressing zone range calculation results for rock strata adjacent to longwall B-2 in coal seam 62/1 using FLAC2D (longwall width, $Ls = 250$ m), including the implementation of rock mass degasification level distribution

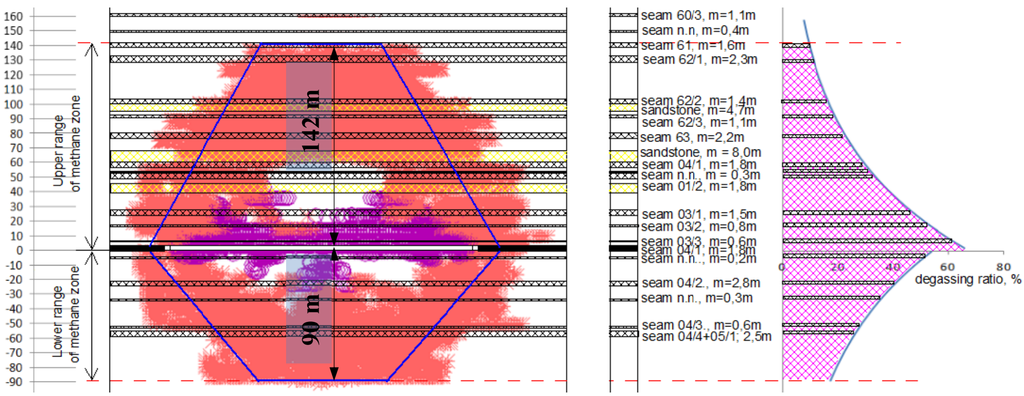

Fig. 6. Destressing zone range calculation results for rock strata adjacent to longwall E-4 in coal seam 04/1 using FLAC2D (longwall length, $Ls = 206$ m), including the implementation of rock mass degasification level distribution

depending on the distance relative to the mined deposit (Kozłowski & Grabski, 1982). Relationships no. 14 and 15 presented in Table 6 were used for this purpose.

In FLAC2D, one of many indices that can be used to assess the state of the numerical model is the plasticity index. It determines the failure possibility of individual rock mass points as a result of tensile or shear stresses. Each type is designated by a different colour on the plot. The shear failure zone is marked with an '*' in red and the tensile failure zone is marked with an 'o' in pink. The plot also indicates whether the zone had failed earlier in the model run, but now the stresses fall below the yield surface, which is marked with an 'x' in green.

The FDM numerical calculation results for the rock mass fracturing zones adjacent to the longwall workings demonstrate that the greatest rock fracturing zone range for both the roof and floor rock can be found in longwall B-2 in coal seam 62/1 (h_g = 169 m, h_d = 105 m). Whereas the shortest range can be found in longwall A-2 in coal seam 62/3+63 (h_g = 133 m, h_d =72 m). The performed FDM calculation results have, therefore, confirmed the dependence of the increase in destressing zone range on the longwall length for both roof and floor strata. Table 7 presents a comparison of the destressing zone range calculation results for the FDM calculations and the empirical method (according to GIG Instruction No. 14).

TABLE 7

Destressing zone range results for the FDM and empirical method calculations

Longwall length *Ls*, m	**Upper destressing (desorption) zone range, h_g**		**Lower destressing (desorption) zone range, h_d**	
	empirical method	**FDM**	**empirical method**	**FDM**
186	128	133	48	72
250	172	169	64	105
206	142	142	53	90

The comparative analysis demonstrates strong concurrence for the upper destressing zone range calculation results. The difference in the upper destressing zone ranges calculated using the two methods does not exceed 5 m. The FDM calculation results are in line with the results provided in literature (Whittles et al., 2006).

Significant differences between the two calculation methods are apparent in the lower destressing zone range. It can also be observed that these differences increase with the increase in the analysed longwall length. For example, the lower range for the longest longwall (Ls = 250 m) is approximately 40 m greater in the case of FDM calculations.

In addition to the aforementioned differences, there are also significant discrepancies in the destressing zone shape obtained using FDM calculations, which consequently has an influence on the coal seam degasification zone width (parameters X_g and X_d, relationships (3) and (4)) and ultimately on the volume of the destressed deposit.

A modification of the zone shape model can be implemented to evaluate the FDM calculation results and parametrise the obtained destressing zone (Fig. 7).

The parameters presented in the modified destressing zone model (Fig. 7) denote:

- h_g, h_d – upper and lower destressing zone ranges, m,
- a, b – overlaying and underlaying coal seam distance from the mined coal seam, m,
- X_g, X_d – overlaying (underlaying) stratum width within the destressing zone (degasification zone width), m.

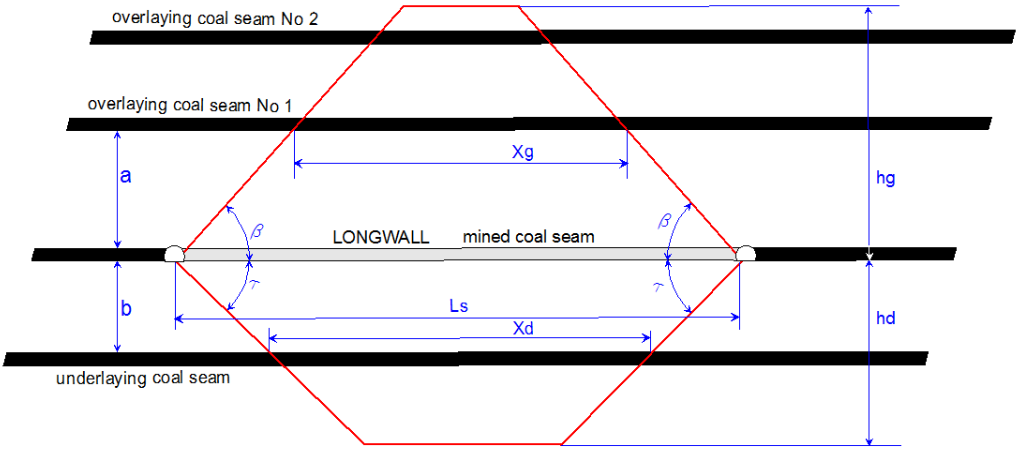

Fig. 7. Simplified destressing zone range in a vertical section along the longwall length – obtained based on FDM modelling results

Similarly to formulas (1) and (2), the following auxiliary factors that enable the determination of both the degasification zone ranges and the widths of the strata present within these zones were implemented to define the model parameters: G_{gMES-1}, G_{dMES-1}, G_{gMES-2}, G_{dMES-2}.

The destressing zone range for overlaying coal seams can be derived from relationship (13), whereas relationship (14) can be applied to underlaying coal seams.

$$h_g = \frac{Ls}{G_{gMES-1}}, \quad \text{m} \tag{13}$$

$$h_d = \frac{Ls}{G_{dMES-1}}, \quad \text{m} \tag{14}$$

Assuming that the coal seam deposition conditions within the destressing zone are fulfilled, i.e. $a < h_g$ and $b < h_d$, the destressing zone width, with reference to the overlaying coal seam stratum, can be calculated using formula (15) and using formula (16) for the underlaying coal seam.

$$X_g = Ls - G_{gMES-2} \cdot a, \quad \text{m} \tag{15}$$

$$X_d = Ls - G_{dMES-2} \cdot a, \quad \text{m} \tag{16}$$

Based on the FDM numerical calculations, the G_{gMES-1} and G_{dMES-1} factors related to destressing zone range determination are independent of longwall length and amount to:

- $\boldsymbol{G_{gMES-1}}$ **= 1.45** for overlaying strata,
- $\boldsymbol{G_{dMES-1}}$ **= 2.40** for underlaying strata.

In the case of destressing zone width factors (G_{gMES-2}, G_{dMES-2}), their obtained values differed greatly depending on the FDM longwall model – the values assigned to specific longwalls are presented in Table 8, which also presents the angle of inclination for the side boundary lines (roof and floor) of the destressing zone, relative to the horizontal plane.

TABLE 8

Comparison the destressing zone width, depending on the adopted calculation method

—	Indices/ Parameters	Longwall A-2	Longwall B-2	Longwall E-4	Average value
For roof strata	$G_{gMES\text{-}2}$	1.10	1.20	0.75	1.02
For floor strata	$G_{dMES\text{-}2}$	1.10	1.40	0.85	1.12
For roof strata	angle b	61.2°	59.0°	69.5°	63.0°
For floor strata	angle t	61.2°	55.0°	67.0°	61.2°

To compare the destressing zone width, depending on the adopted calculation method, Table 9 presents the calculated values for a 200 m-long longwall as well as the values adopted for the empirical method: $G_g = 1.45$, $G_d = 3.91$ and FDM calculations: $G_{gMES-1} = 1.45$, $G_{dMES-1} = 2.40$, $G_{gMES-2} = 1.02$, $G_{dMES-2} = 1.12$.

TABLE 9

Comparison the destressing zone width, depending on the adopted calculation method

No.	Coal seams	Distance from the mined coal seam	FDM calculations (h_g = 138 m) (h_d = 83 m)	Empirical method (h_g = 138 m) (h_d = 51 m)	Difference
1	Underlaying coal seam 1	20 m	179 m	170 m	9 m
2	Underlaying coal seam 2	60 m	140 m	111 m	29 m
3	Underlaying coal seam 3	100 m	98 m	51 m	47 m
4	Overlaying coal seam 1	20 m	178 m	122 m	56 m
5	Overlaying coal seam 2	50 m	144 m	5 m	139 m
6	Overlaying coal seam 3	80 m	110 m	0	110 m

The differences between destressing zone widths presented in Table 9 demonstrate that supporting the forecasting with FDM-determined destressing zones will have an influence on the increase in the volume of the destressed rock mass, and consequently on the increase in forecast values for methane desorbed to the longwall environment from overlaying and underlaying coal seams.

5. Calculation results for desorbed methane volumes in the longwall environment and the forecast longwall absolute methane emission rate depending on extraction and daily advance

The destressing (degasification) zones obtained by means of numerical modelling were compared to the guidelines defined in Instruction No. 14 (GIG Instruction, 2000) concerning the degasification levels for overlaying and underlaying strata (Kozłowski & Grabski, 1982). Based on the coal seam methane content measurement results, interpolated results for untested strata and the adopted assumptions for the degasification level and destressing zone range, desorbed methane volumes were calculated for the methane-bearing roof and floor strata. The desorbed methane volume calculations for 3 longwall environments are presented in Table 10.

TABLE 10

The desorbed methane volume calculations for 3 longwall environments

Longwall	Methane source	Volume based on FDM, m^3CH_4	Volume based on the empirical method, m^3CH_4	Methane volume difference, m^3CH_4
A-2	Overlaying strata	203 848	164 747	39 101
	Underlaying strata	563 573	164 223	399 401
B-2	Overlaying strata	218 608	202 531	16 077
	Underlaying strata	739 744	430 377	309 367
E-4	Overlaying strata	182 236	145 519	36 717
	Underlaying strata	472 480	149 354	323 126

The comparison of methane volumes (Table 10) estimated on the basis of the algorithm included in GIG Instruction no. 14 and the implemented FDM modelling results demonstrate that the desorbed methane volumes based on FDM are 1.5 to 2.3 times greater for the analysed longwalls compared to the empirical method results. It should, however, be noted that the main reason for the increase in volumes calculated using FDM are the increased destressing zones in floor strata and the relatively higher methane content values for underlaying coal seams compared to overhand coal seams, which are typically characterised by lower remaining methane content (influence of higher-deposited coal seam extraction). The FDM-determined methane volumes in floor strata are 1.7 to 3.4 times greater compared to the empirical method results.

The calculations of forecast longwall absolute methane emission rates and methane emissions from adjacent strata based on empirical relationships and implemented destressing zones obtained from FDM numerical simulations are compiled in Tables 11-12. The tables also present absolute and relative differences between the forecast values.

Comparison of the values in Tables 11-12 reveals that the differences in forecast methane emission rates from adjacent strata to the longwall environments are similar to the methodologically estimated desorbed methane volumes – i.e. they are 1.5 to 2.3 times greater for FDM

TABLE 11

Longwall absolute methane emission rate forecasting results depending on daily extraction output and the applied forecasting method

No.	Longwall, coal seam	Forecasting method	Daily output, Mg/d			
			1000	2000	3000	4000
1	2	3	4	5	6	7
1	A-2 seam 62/3+63	Empirical method	6.81 m^3CH_4/min	11.78 m^3CH_4/min	16.34 m^3CH_4/min	20.67 m^3CH_4/min
		FDM simulations	12.52 m^3CH_4/min	20.91 m^3CH_4/min	28.37 m^3CH_4/min	35.31 m^3CH_4/min
		Difference, m^3CH_4/min	5.71	9.13	12.03	14.64
		Relative difference, %	84	78	74	71

1	2	3	4	5	6	7
2	B-2 seam 62/1	Empirical method	11.62 m^3CH_4/min	19.47 m^3CH_4/min	26.45 m^3CH_4/min	32.94 m^3CH_4/min
		FDM simulations	16.65 m^3CH_4/min	27.52 m^3CH_4/min	37.06 m^3CH_4/min	45.85 m^3CH_4/min
		Difference, m^3CH_4/min	5.03	8.05	10.61	12.91
		Relative difference, %	43	41	40	39
3	E-4 seam 04/1	Empirical method	6.59 m^3CH_4/min	11.14 m^3CH_4/min	15.21 m^3CH_4/min	19.02 m^3CH_4/min
		FDM simulations	11.31 m^3CH_4/min	18.69 m^3CH_4/min	25.16 m^3CH_4/min	31.12 m^3CH_4/min
		Difference, m^3CH_4/min	4.72	7.55	9.95	12.1
		Relative difference, %	72	68	65	64

TABLE 12

Forecasting results for methane emission rates from roof and floor strata depending on daily extraction output and the applied forecasting method

No.	Longwall, coal seam	Forecasting method	Daily output, Mg/d			
			1000	2000	3000	4000
1	A-2 seam 62/3+63	Empirical method	3.56 m^3CH_4/min	5.71 m^3CH_4/min	7.52 m^3CH_4/min	9.15 m^3CH_4/min
		FDM simulations	8.32 m^3CH_4/min	13.32 m^3CH_4/min	17.55 m^3CH_4/min	21.34 m^3CH_4/min
		Difference, m^3CH_4/min	4.76	7.61	10.03	12.19
		Relative difference, %	133			
2	B-2 seam 62/1	Empirical method	7.67 m^3CH_4/min	12.29 m^3CH_4/min	16.19 m^3CH_4/min	19.68 m^3CH_4/min
		FDM simulations	11.86 m^3CH_4/min	19.00 m^3CH_4/min	25.03 m^3CH_4/min	30.44 m^3CH_4/min
		Difference, m^3CH_4/min	4.19	6.71	8.84	10.76
		Relative difference, %	54			
3	N-4 seam 04/1	Empirical method	4.17 m^3CH_4/min	6.68 m^3CH_4/min	8.80 m^3CH_4/min	10.71 m^3CH_4/min
		FDM simulations	8.10 m^3CH_4/min	12.98 m^3CH_4/min	17.10 m^3CH_4/min	20.79 m^3CH_4/min
		Difference, m^3CH_4/min	3.93	6.30	8.30	10.08
		Relative difference, %	94			

calculations compared to the empirical method results, regardless of the daily extraction output. As for the total absolute methane emission rate forecast, it is approximately 1.4-1.7 times greater for FDM calculations, and the difference is greater for lower daily extraction outputs.

6. Underground measurement results and accuracy verification for FDM and empirical forecasting

The results of the tests of methane concentrations (n_1, n_2, n_3), air flow rates (Q_1, Q_2, Q_3) and methane capture to the drainage network (Qo), as well as the total longwall environment absolute methane emission rate ($Qc(rej)$) calculations, obtained from measurements, and the methane emission rates from overlaying and underlaying strata ($Q(des)$) are compiled in Table 13.

TABLE 13

Ventilation and methane parameter measurement results, calculated total longwall environment absolute methane emission rate values $Qc(rej)$ and methane emission rates from overhand and underhand coal seams

Long-wall	Test date, month	Longwall face distance	Average daily extraction, Wd	Measurement results							Calculation results	
				Q_1	n_1	Q_2	n_2	Q_3	n_3	Qo	$Qc(rej)$	$Q(des)$
—	—	m	Mg/d	m^3/min	% CH_4	m^3/min	% CH_4	m^3/min	% CH_4	m$^3CH_4$/min	m$^3CH_4$/min	m$^3CH_4$/min
A-2	3rd	220	3178	1370	0.43	1370	0.84	2970	0.86	12.2	**31.85**	**26.23**
A-2	4th	325	3698	1370	0.30	1370	0.89	2975	0.80	10.8	**30.49**	**22.41**
A-2	5th	405	3009	1370	0.22	1370	0.59	2985	0.68	11.7	**28.98**	**23.92**
A-2	6th	485	2710	1375	0.27	1375	0.61	2990	0.68	10.6	**27.22**	**22.54**
B-2	7th	520	2371	1375	0.21	1375	0.69	2985	0.92	8.3	**32.87**	**26.27**
B-2	7th	265	1391	1310	0.00	1310	0.80	2335	0.99	7.5	**30.62**	**20.14**
B-2	8th	280	923	1250	0.00	1250	0.42	2200	0.83	6.7	**24.96**	**19.71**
B-2	9th	295	894	1020	0.00	1020	0.32	1720	0.75	4.9	**17.80**	**14.54**
B-2	10th	365	2753	1025	0.00	1025	0.49	1735	0.72	5.1	**17.59**	**12.57**
B-2	11th	460	3204	1038	0.00	1038	0.75	1743	0.74	6.3	**19.20**	**11.41**
B-2	12th	525	2881	1030	0.00	1030	0.57	1735	0.63	9.5	**20.43**	**14.56**
B-2	13th	575	1691	1037	0.00	1037	0.45	1722	0.50	9.0	**17.61**	**12.94**
B-2	15th	605	758	825	0.00	825	0.30	1505	0.39	1.3	**7.17**	**4.69**
E-4	3rd	330	3105	1025	0.19	1025	0.67	1725	0.86	9.00	**21.89**	16.97

The possibility assessment for utilising numerical rock strata degasification zone range determination methods in methane emission rate forecasting in longwall environments was conducted based on the comparative result analysis of total absolute methane emission rate forecasting and desorbed methane emission rate forecasting from adjacent strata within the destressing zones with measurement results of actual absolute methane emission rates and methane emissions from adjacent strata. The analysis encompassed longwall extraction cycles, where the panel length exceeded 200 m, ensuring the achievement of the full scope of the destressing zone. Downtimes were also discarded, e.g. the lack of extraction in longwall B-2 and coal seam 62/1 in the 16th month. The 6th month was also discarded for this longwall, as it involved driving the longwall face through a zone of geological disturbances (faults), which resulted in low daily advance, as well as the occurrence of a local source of additional methane emissions to the longwall, which is not included in forecasting. The comparative forecasting results according to GIG Instruction no. 14 and FDM calculations, including the absolute and relative forecasting errors, are compiled in Table14-15.

TABLE 14

Longwall total absolute methane emission rate forecasting results by means of the empirical method and FDM calculations compared to the measured total absolute methane emission rates

Longwall	Month	Average daily extraction, *Wd*	Measured *Qc*(*rej*)	Method	Forecast *Qc*(*rej*)	Absolute error	Relative error
—	—	Mg/d	m^3/min	—	m^3/min	m^3/min	%
A-2	3rd	3178	31.85	empir.	29.29	–2.56	–0.08
				FDM	42.84	**10.99**	0.35
A-2	4th	3698	30.49	empir.	19.38	**–11.11**	–0.36
				FDM	33.26	2.77	0.09
A-2	5th	3009	28.98	empir.	25.87	–3.11	–0.11
				FDM	38.97	9.99	0.34
A-2	6th	2710	27.22	empir.	20.36	–6.86	–0.25
				FDM	31.91	4.69	0.17
A-2	7th	2371	32.87	empir.	17.44	**–15.43**	–0.47
				FDM	28.14	–4.73	–0.14
B-2	7th	1391	30.62	empir.	15.01	–15.61	–0.51
				FDM	21.15	–9.47	–0.31
B-2	8th	923	24.96	empir.	11.08	–13.88	–0.56
				FDM	15.70	–9.26	–0.37
B-2	9th	894	17.80	empir.	10.82	–6.98	–0.39
				FDM	15.35	–2.45	–0.14
B-2	10th	2753	17.59	empir.	15.23	–2.36	–0.13
				FDM	23.38	5.79	0.33
B-2	11th	3204	19.20	empir.	17.14	–2.06	–0.11
				FDM	26.11	6.91	0.36
B-2	12th	2881	20.43	empir.	15.74	–4.69	–0.23
				FDM	24.16	3.73	0.18
B-2	13th	1691	17.61	empir.	10.57	–7.04	–0.40
				FDM	16.43	–1.18	–0.07
B-2	15th	758	7.17	empir.	1.15	–6.02	**–0.84**
				FDM	9.25	2.08	0.29
E-4	3rd	3105	21.89	empir.	15.62	–6.27	–0.29
				FDM	25.81	3.92	0.18

The absolute methane emission rate calculations performed using the empirical method demonstrate that forecasting error exceeding 10 m^3CH_4/min occurred 4 times for the empirical method, whereas for FDM calculations it occurred only once. Considering the percentage difference between the values (relative forecasting error), errors exceeding 50% occurred only in forecasts performed using the empirical method (3 results).

TABLE 15

Forecasting results for emitted methane volumes desorbed from adjacent strata to the longwall environment, obtained by means of the empirical method and FDM calculations compared to the measured methane emission rates from adjacent strata

Longwall	Month	Average daily extraction, Wd	Measured Q(des)	Method	Forecast Q(des)	Absolute error	Relative error
—	—	Mg/d	m^3/min	—	m^3/min	m^3/min	%
A-2	3rd	3178	26.23	empir.	14.40	**–11.83**	–0.45
				FDM	25.70	–0.53	–0.02
A-2	4th	3698	22.41	empir.	8.67	–13.74	–0.61
				FDM	20.23	–2.18	–0.10
A-2	5th	3009	23.92	empir.	12.67	**–11.25**	–0.47
				FDM	23.56	–0.36	–0.01
A-2	6th	2710	22.54	empir.	9.96	**–12.58**	–0.56
				FDM	19.58	–2.96	–0.13
A-2	7th	2371	26.27	empir.	8.59	–17.68	–0.67
				FDM	17.52	–8.75	–0.33
B-2	7th	1391	20.14	empir.	9.63	**–10.51**	–0.52
				FDM	14.74	–5.40	–0.27
B-2	8th	923	19.71	empir.	7.23	–12.48	–0.63
				FDM	11.14	–8.57	–0.43
B-2	9th	894	14.54	empir.	7.13	–7.41	**–0.51**
				FDM	10.91	–3.63	–0.25
B-2	10th	2753	12.57	empir.	9.63	–2.94	–0.23
				FDM	16.42	3.85	0.31
B-2	11th	3204	11.41	empir.	10.71	–0.70	–0.06
				FDM	18.21	6.80	**0.60**
B-2	12th	2881	14.56	empir.	9.93	–4.63	–0.32
				FDM	16.94	2.38	0.16
B-2	13th	1691	12.94	empir.	6.91	–6.03	–0.47
				FDM	11.79	–1.15	–0.09
B-2	15th	758	4.69	empir.	0.83	–3.86	**–0.82**
				FDM	6.83	2.14	0.45
E-4	3rd	3105	16.97	empir.	9.01	–7.96	–0.47
				FDM	17.50	0.53	0.03

In the case of forecast methane emission rates from adjacent strata, it should be noted that no FDM forecasting result provided a difference exceeding 10 m^3CH_4/min, whereas such a difference occurred in nearly half of the empirical forecasting results. As for the analysis of relative errors at a level of 50%, FDM forecasting provided one such result, whereas the empirical method yielded 5 results, including one exceeding a level of 80%.

To summarise, it can be concluded that FDM forecasting is characterised by greater accuracy compared to the empirical method. Similar conclusions can be drawn by analysing the average error values (Table 16).

TABLE 16

Average forecasting error results

	Methane emission rate forecast		Forecast methane inflow from adjacent strata	
	Empirical method	FDM	Empirical method	FDM
Average absolute error, m^3CH_4/min	7.4 m^3CH_4/min	5.6 m^3CH_4/min	8.8 m^3CH_4/min	3.5 m^3CH_4/min
Average relative error	0.34	0.23	0.49	0.22

The lower average value of the absolute error for forecasting based on FDM numerical modelling also confirms that the results obtained by means of FDM forecasting correspond better to the actual results. It can, therefore, be assumed that the addition of FDM-determined destressing zones to the forecasting algorithm will increase the reliability of forecasts concerning both total absolute methane emission rates and emission rates from adjacent strata. Fig. 8 presents a graphical interpretation of the forecast values with measured values. The charts presented demonstrate that the current forecasts concerning longwalls developed under low rock mass geomechanical parameter conditions are underestimated, and in most cases their results are lower than the actual values.

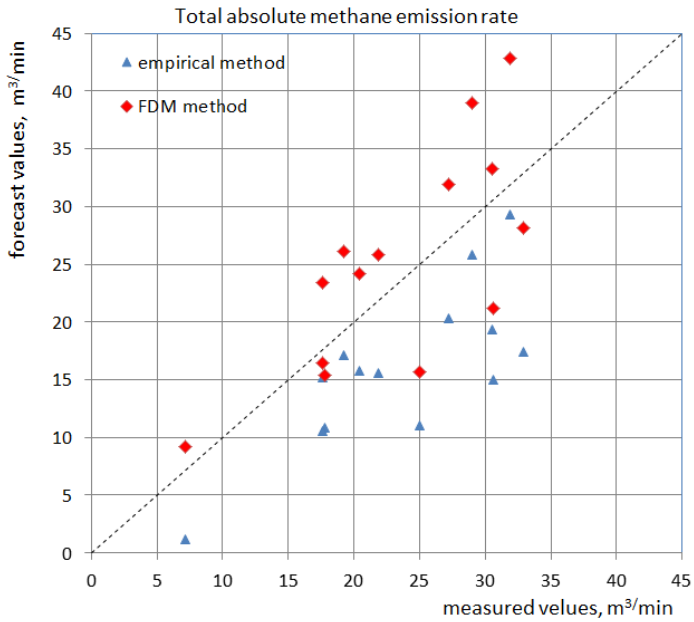

Fig. 8. Comparison of measured total longwall absolute methane emission rate values with values forecast according to the empirical method and FDM calculations

The above observation further confirms the necessity to factor in the destressing zone range, resulting from the geomechanical parameters of the mined coal seam and of the rock strata deposited adjacent to the longwall extraction.

Therefore, it is necessary for research to continue in terms of degasification zone verification (particularly within the scope of floor strata) depending on rock geomechanical parameters, longwall working geometry, coal seam inclination and mining depth. There is also a necessity to conduct research in order to find new relationships that describe how the degasification zone ranges of adjacent strata depend on the aforementioned parameters.

7. Conclusions

1. The comparative analysis of forecasting results based on an empirical destressing zone range determination method (i.e. without including the rock mass geomechanical parameters) (GIG Instruction, 2000) with measured methane emission rates in longwalls developed in a rock mass characterised by low strength parameters demonstrates that these forecasts exhibit an average underestimation of 66%.
2. Analysis results show that numerical FDM (finite difference method) calculations can be used effectively for the purposes of destressing zone determination that factors in rock mass geomechanical parameters.
3. The overlaying stratum destressing zone range analysis proved that the range is 50-70% greater for floor strata with low strength parameters compared to the assumptions adopted in the currently employed longwall absolute methane emission rate forecasting method. For example, for a 250 m-long longwall, the range calculated using FDM forecasting was 105 m and this was approximately 40 m greater than the 64 m zone range obtained using the empirical method defined in (GIG Instruction, 2000).
4. Methane emission rate forecasting should factor in the destressing zone range resulting from the geomechanical parameters of the mined coal seam and of the rock strata deposited adjacent to the conducted longwall extraction. This is confirmed by the comparative forecasting analysis results, where the inclusion of geomechanical parameters makes it possible to increase forecasting accuracy by reducing the number of forecasts characterised by a relative error exceeding the threshold of 50%, as well as by reducing the average relative forecasting error from 34% to 23%. It means the proposed of numerical modelling method improve the accuracy of the forecast.
5. Auxiliary factor values proposed in the article, i.e. $G_{gMES-1} = 1.45$ and $G_{dMES-1} = 2.40$, which concern destressing zone height determination for roof and floor strata, can be used for the purposes of destressing zone determination for longwalls with minor transverse inclination (up to 5°) that are developed in a rock mass characterised by low strength parameters. Due to the wide spread of the G_{gMES-2} and G_{dMES-2} factor values concerning destressing zone width, research should be continued in order to determine the parameters that influence them. It is also recommended that research be conducted in terms of determining the values of the aforementioned factors for greater longwall inclinations.

Acknowledgement

The article was written as part of the statutory work Central Mining Institute in Katowice No. 11132029-211, titled "Degasification zone range determination using numerical modelling for rock strata adjacent to longwalls", financed by the Ministry of Science and Higher Education.

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