

Stanisław Nawrat, Sebastian Napieraj**

USE OF SIMULATION FOR ASSESSMENT OF THE POSSIBILITIES OF CREW EVACUATION IN MINES

1. Introduction

In underground mines, in case of the hazard occurrence, for example fire occurrence, action of evacuation of mining crew from hazardous zones is executed. Decisive factors deciding about success of the mining crew evacuation comprises selection of optimal escape routes and evacuation time. These factors have not been studied so far because of the lack of suitable computer softwares. Assessment of the possibilities of numerical modelling application for designing the mining crew evacuation from hazardous mine zones has been presented in this study.

Design of safe evacuation of the mining crew from hazardous zone in case of the fire occurrence is one of the aims of the mine rescue work.

According to article No. 75 of the Geological and Mining Law, the employer should possess well organized mining rescue works. Each mine should develop and realize, if needed, the rescue plan. Manner of the realisation of the rescue action in case of crew or equipment hazard should be determined in the rescue plan. Scheme of escape routes for each mine zone, where for example fire can occur, is prepared for purpose of the mining crew evacuation from hazardous zones. Manner and duration of the crew evacuation from hazardous zones is defined in the escape routes scheme.

Development of the crew evacuation from hazardous zones is a very complicated problem, and so far, great simplifications were made in order to determine crew evacuation duration.

* AGH University of Science and Technology, Krakow

Numerical modelling methods taking under consideration individual features and decision making processes, crowd dynamics, panic and interactions between evacuated crew during evacuation can be considered in preparing evacuation plans. Numerical modelling and numerical simulations comprise one of the few means allowing evacuation process management already in the phase of designing the mine workings in objective and national way.

2. Model of the crew evacuation from the longwall zone

Program Fire Dynamics Simulator with addition Evacuation was used for preparation the crew evacuation from the longwall zone. This program allows modelling of the crew evacuation from hazardous zone.

Helbling's evacuation model used as main algorithm for the crew movement together with modification proposed by Helbing was used in simulation software FDS.

Symulator FDS (*Fire Dynamics Simulator*), which allows obtaining information about the fire propagation including data relating to physical and chemical properties of gases, visibility, radiation etc., what is necessary to characterize evacuation conditions were used for defining the influence of the fire and smoke dynamics onto the mode of crew evacuation.

Individual features relating to movement speed, size, time of reaction to the hazard, knowledge of terrain topography, knowledge of escape routes etc are prescribed to each evacuated worker.

3. Simulation of the crew evacuation from the longwall zone

In numerous Polish mines occurs methane hazard what can be a reason of fires and methane explosions (for example in Krupiński coal mine). Fires or methane explosions may occur in mine workings, for example in left roadways, longwall mine workings, right roadways. Occurrence of fire in a left roadway, what allowed crew evacuation toward inclined drift from the right roadway side was assumed in the presented material.

The wall is exploited in longitudinal longwall system with roof cut and fill. The longwall was ventilated with use of system U (Fig. 1).

Occurrence of fire in the right roadway was assumed in the described model.

3.1. Model assumptions

The longwall zone model is characterized with the following parameters:

— Geometrical parameters:

- Inclined drift of the length 250 m;
- Right roadway of the length 500 m, cross-section 11 m²;
- Left roadway of the length 500 m cross section 11 m²;
- Longwall mine working of the length 206 m, cross-section 14 m².

- Ventilation parameters:
 - Ventilation system „U” from the field;
 - Air flow rate in longwall mine working 1500 m³/min;
 - Air flow rate in ventilation region 1800 m³/min.
- Fire sources:
 - Localization of the fire source — at 200 m of the right roadway;
 - Fire propagation: from 0MW to maximal fire thermal power (optional: A, B, C and D) time constant of fire development — 60 s;
 - Fire thermal power optional: A — 1 MW, B — 2 MW, C — 3 MW and D — 4 MW.
- Number of persons mine working in longwall zone:
 - In right roadway — 4 workers;
 - In longwall mine working — 10 workers;
 - In left roadway — 8 workers.

System of mining mine workings for a period of fire propagation and crew evacuation $t = 120$ s for variant B is show in Figure 2.

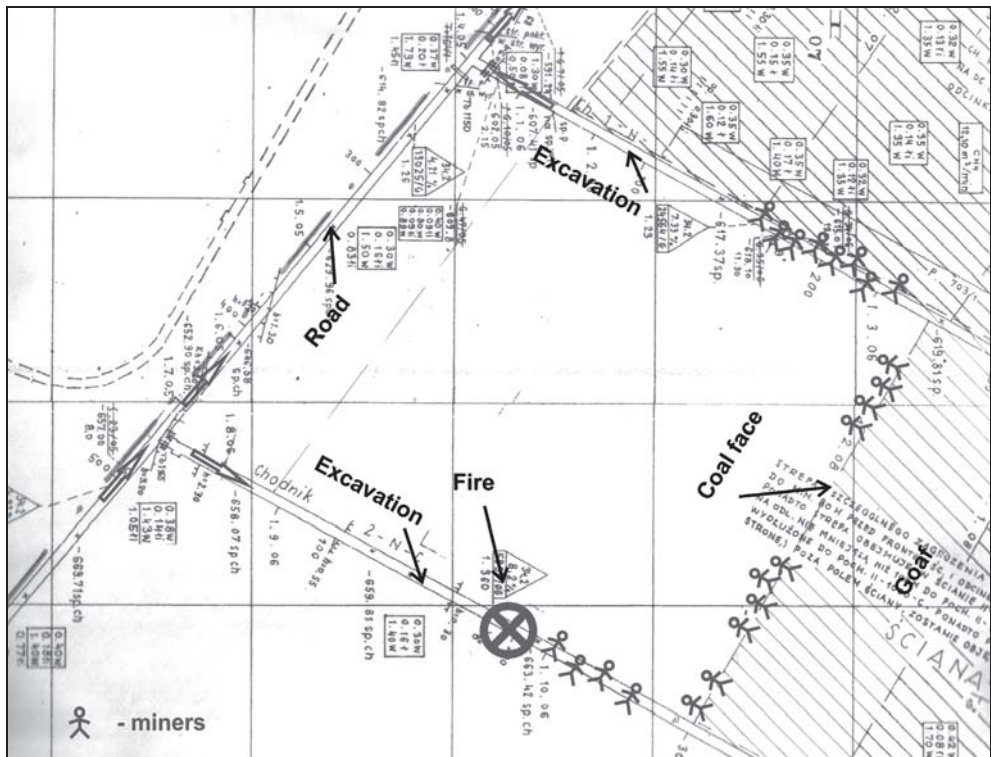


Fig. 1. Scheme of mining mine workings of the crew evacuation model

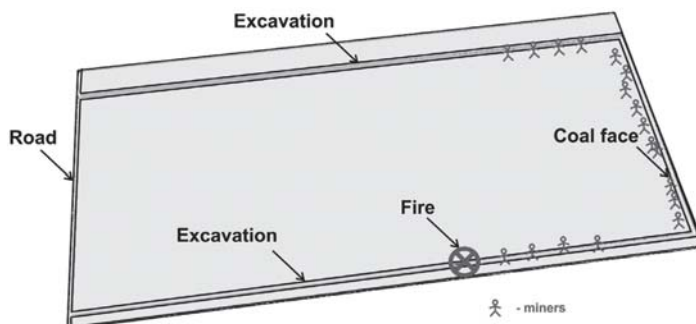


Fig. 2. Model of mine workings in programme FDS + EVAC

Figure 3 presents a visualization of the crew evacuation at $t = 60$ s for variant B.

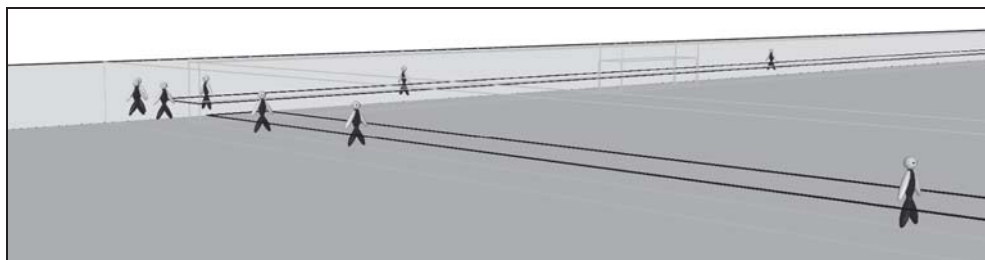


Fig. 3. Simulation of fire and evacuation

3.2. Evacuation parameters

Suitable model examinations for assumed fire thermal powers 1, 2, 3 and 4 MW (variants A, B, C, and D respectively), which allowed calculation of time needed for the crew evacuation in dependence on fire size, fire dynamics and evacuation conditions (distribution of mining workings and individual features of workers) have been executed in order to test the crew evacuation from the longwall zone in case of fire occurrence.

It was assumed for each variant that time of the fire development up to reaching its full thermal power amounts for 60 s. Results of executed examinations presented in graphical form, which illustrate number of workers present in hazardous zone in dependence of the time are show in Figure 4.

Statistical analysis executed in order to determine the relation between fire power and crew evacuation time has been made for variants A, B, C and D. The analysis proved a relation between fire power and evacuation time (Fig. 5).

Figure 4 — Relation between number of persons present in hazardous zone and crew evacuation time.

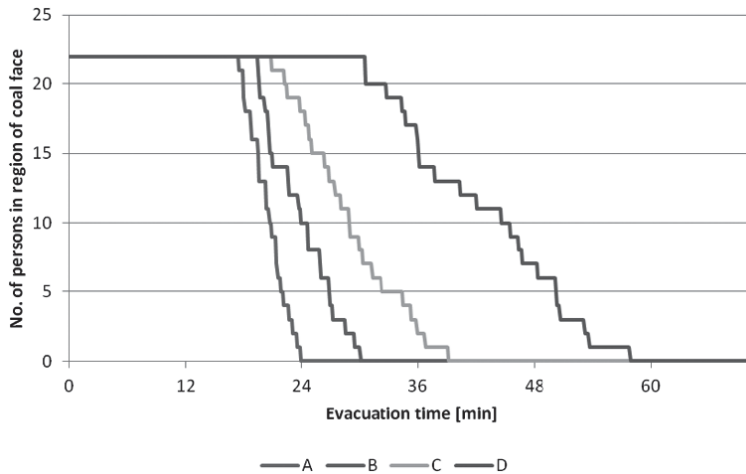


Fig. 4. Number of persons in the threatened area of the mine, depending on the time of evacuation

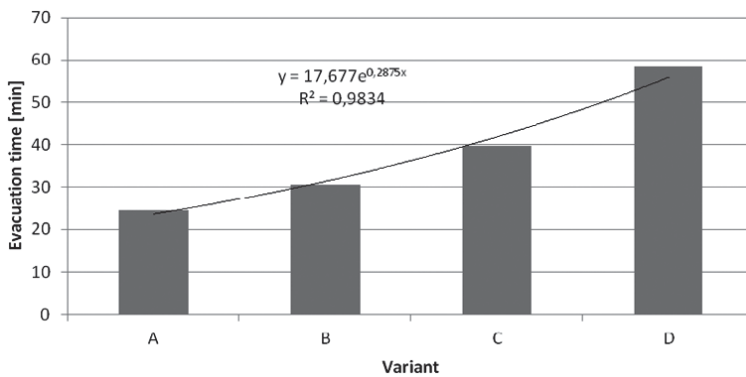


Fig. 5. Time needed for crew evacuation in dependence on the fire thermal power

4. Conclusions

The presented material allows drawing the following conclusions:

- 1) Suitable escape roads should be determined already in phase of mine workings designing in order to assure safe crew evacuation from hazardous zone, for example fire occurrence.
- 2) Simulation programs allowing optimal selection of the escape road and crew evacuation, including evacuation time can be successfully used.
- 3) Fire thermal power and resulting smokiness and time constant of the fire propagation have considerable influence onto crew evacuation time.

- 4) The time needed for the crew evacuation increases in exponentially in dependence on the fire power, what for a case discussed in the present study was described with equation $y = 17.677 e^{0.2875x}$ at very high correlation factor $R = 0.9834$
- 5) Simulation taking into consideration local conditions and parameters of the fire source should be performed each time when the detailed algorithms for the crew evacuation are made.
- 6) Modelling of the crew evacuation from the hazardous zone, for example fire hazard allows:
 - Making analysis and assessing possibilities of the crew evacuation in defined time, for example limited time of self-rescue apparatus;
 - Optimization of escape roads according to individual personal features of each crew member, terrain obstacles (dip, distance) and other difficulties, like obstacles and smokiness;
 - Visualization of the crew evacuation process in case of the fire propagation, what is very helpful in designing and the mining crew training.
- 7) Further examinations concerning model validation for mine conditions are necessary.

REFERENCES

- [1] *Harri Ehtamo, Simo Heliovaara, Simo Hostikka, Timo Korhonen*: Modeling Evacuees' Exit Selection with Best Response Dynamics 4th Intl. Conference on Pedestrian and Evacuation Dynamics, 27–29 Feb, 2008.
- [2] *Nawrat S., Kuczera Z., Napieraj S.*: Badania modelowe zwalczania zagrożenia metanowego na wylocie ściany przewietrzanej systemem „U” — Model research relating to methane hazard fighting at face end ventilated by „U” system/W: Materiały 4 Szkoły Aerologii Górniczej = Proceedings of the 4th School of Mine Ventilation : Kraków, 10–13 październik 2006 / Sekcja Aerologii Górniczej Komitetu Górnictwa PAN [etc.] — Katowice: Centrum Elektryfikacji i Automatykacji Górnictwa EMAG, cop. 2006 — Na okł. dod.: 4 Szkoła Aerologii Górniczej. Sekcja Aerologii Górniczej. Komitet Górnictwa PAN. Kraków — S. 455–465 — Bibliogr. s. 465.
- [3] *Nawrat S., Napieraj S.*: Metoda projektowania systemu kompleksowego zwalczania zagrożenia metanowego w ścianach w kopalniach węgla kamiennego — [The method of complex system design of methane hazard fighting in longwalls in coalmines] /W: ROP'2006: zwalczanie zagrożenia metanowego oraz wyrzutami gazów i skał — teoria i praktyka: XXIII seminarium: XXXII Dni Techniki: Rybnik, 26 października 2006 r. /Naczelna Organizacja Techniczna, Stowarzyszenie Inżynierów i Techników Górnictwa — Gliwice: Wydział Górnictwa i Geologii Politechniki Śląskiej. Instytut Eksploatacji Złóż, [2006] — S. 83–98 — Bibliogr. s. 98.
- [4] *Nawrat S., Napieraj S.*: Możliwość i wykorzystania programów komputerowych CFD w wentylacji kopalń podziemnych — Possibilities of CFD computer software utilisation in underground mines ventilation/ Wiadomości Górnicze; ISSN 0043-5120 — 2006 R. 57 nr 9 s. 449–457 — Bibliogr. s. 457.
- [5] *Nawrat S., Napieraj S.*: Systems of fighting against methane threat in coal mines/W: The 1st China international conference proceedings on Coal mine gas control & utilization : October 26–27, 2005, Beijing, P. R. China / eds. Li Yizhong [et al.] — Beijing: Coal Industry Publishing House, 2005 — S. 224–232 — Bibliogr. s. 232.
- [6] *Timo Korhonen, Simo Hostikka, Simo Heliovaara, Harri Ehtamo*: FDS+Evac: An Agent Based Fire Evacuation Model 4th Intl. Conference on Pedestrian and Evacuation Dynamics, 27–29 Feb, 2008.