www.czasopisma.pan.pl PAN www.journals.pan.pl

VERSITA

Arch. Min. Sci., Vol. 58 (2013), No 1, p. 217–226

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

DOI 10.2478/amsc-2013-0015

HOSSEINI SEYED MEHDI*, MIKAEIL REZA**, ATAEI MOHAMMAD*,
REZA KHALOKAKAEI*, MASOUD AKHYANI*

DEVELOPMENT A NEW CLASSIFICATION FOR ASSESSING THE COAL MINE MECHANIZATION

OPRACOWANIE NOWEJ KLASYFIKACJI DLA OCENY MECHANIZACJI W KOPALNIACH WĘGLA

The coal mine mechanization is important to achieve optimum quality and maximum efficiency of coal production. Mechanization is an objective that can result in significant cost reductions and higher levels of profitability for underground mines. The potential of coal mine mechanization depends on some important factors Such as seam inclination and thickness, geological disturbances, seam floor conditions and roof conditions. These factors should be considered in coal mine mechanization analysis. In this study, the new classification was developed with the respect to the mentioned factors. Using this system the coal seam mechanization index (CSMi) of several types of coal seams was evaluated and classified into five categories; very good, good, medium, low and very low. As a case study, the mechanization of the Takht coal seams in Golestan area of Iran was investigated using this new classification system. The results show a low potential for mechanization in most of the Takht coal seams.

Keywords: mechanization, coal seams, Classification system, CSMi

Mechanizacja prac w kopalniach węgla jest konieczna dla osiągnięcia maksymalnej wydajności produkcji i uzyskania węgla najwyższej jakości. Mechanizacja jest celem, który skutkować będzie znacznym obniżeniem kosztów oraz zwiększeniem poziomu rentowności produkcji w kopalniach podziemnych. Możliwości mechanizacji w kopalniach uzależnione są od szeregu ważnych czynników, takich jak nachylenie i miąższość złoża, obecność zaburzeń struktury geologicznej a także warunki stropowe i spągowe. Czynniki te koniecznie uwzględnić należy w analizach możliwości mechanizacji pracy kopalni. W pracy tej przedstawiono nową klasyfikację opartą o wyżej wymienione czynniki. W oparciu o przyjęte podejście, obliczony został wskaźnik mechanizacji dla złoża węgla i następnie zastosowany został do analiz. Na jego podstawie wyodrębniono pięć kategorii złóż węglowych w kontekście możliwości mechanicznego urabiania: bardzo dobre, dobre, średnie, niskie i bardzo niskie. Jako studium przypadku przedstawiono analizę złoża węglowego Takht w regionie Golestan w Iranie, w oparciu o zaproponowany nowy system klasyfikacji. Wyniki analizy wskazują, że większość złóż w regionie Takht stwarza niewielkie możliwości dla zastosowania mechanizacji.

Słowa kluczowe: mechanizacja wydobycia, złoże węglowe, system klasyfikacji, wskaźnik mechanizacji dla danego złoża

* DEPARTMENT OF MINING, SHAHROOD BRANCH, ISLAMIC AZAD UNIVERSITY, SHAHROOD, IRAN
** DEPARTMENT OF MINING AND METALLURGICAL ENGINEERING, URMIA UNIVERSITY OF TECHNOLOGY, URMIA, IRAN

1. Introduction

One of the most important tasks in coal mines is to improve efficiency for increasing the production rate of coal besides keeping safety constantly in mind. In order to achieve this aim, mine mechanization is required. Mine mechanization needs high levels of investment and should therefore be studied carefully before final decisions about mechanization are made. For these reasons mining engineers are continuously looking for different ways to mechanize mining procedures, especially the mechanization of underground coal mines that provide a large potential for reduced costs, increased safety and improved profitability. Mechanization and automation are changing the way in which ore deposits are being mined. The industry needs more energy-efficient methods, systems and approaches. For many years, machines have been used to excavate soft minerals in underground mines on a continuous basis. In some cases, this includes soft or weak rocks, surrounding the valuable minerals which are being extracted. Coal is probably the most common example. The methods of working coal seams have gradually evolved and are progressively improved or modified as knowledge and experience are gained and power machines become available. Over the years, a very large number of coal mining methods have been developed to suit seams and local conditions; these may be split broadly into long wall and pillar methods of working. The long wall coal mining method is widely perceived to be a twentieth century development; however, the concept is actually believed to have been developed more than 200 years ago. Its main advance is that earlier operations were, in principle, manual, while since the 1950s, the level of mechanization has increased to the stage that today long wall faces are highly productive units which can be operated by a very small work crew. This method has a simple system layout and provides for continuous production and full potential for mechanization, which can further improve productivity, personnel health and safety. Mechanized long walls rather than other coal mining methods are more expensive to equip and operate, but are in general more productive (Ataei et al., 2009). In this study, the predicting the mechanization of coal seam was investigated by a new classification system. As a case study, the mechanization of Takht coal seams was evaluated using this new classification system.

2. Factors affecting the coal mine mechanization

The potential of coal mine mechanization depends on some important factors. The factors affecting the coal mine mechanization can be divided into tow major parts such as characteristics of seam coal and environmental conditions. The characteristics of coal seam are seam inclination, thickness, uniformity and extension. The environmental conditions that affect on coal seam mechanization are seam floor conditions, roof conditions and water at the working face. These factors are given in Figure 1.

2.1. Seam inclination

Most long wall mining activities occur in flat ore deposits or nearly flat seams. In general, seams with low a dip (zero or near-zero dip angles) are more amenable for mechanization. With increased seam gradients, the application of mechanization becomes more difficult. Although the best operational conditions are on level seams, in rare cases seams with up to 80 degrees of

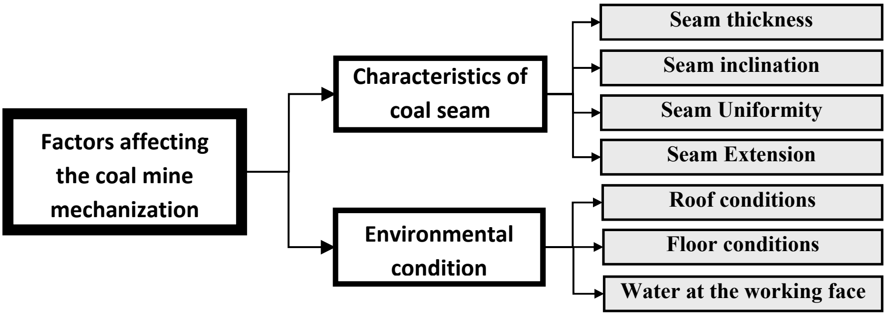

Fig. 1. Parameters used in coal mine classification system

inclination have been worked, although more usually seams up to 35 degree of inclination can be mechanized by power support. The proposed classification for evaluating of seam inclination is given in Table 1.

TABLE 1

Proposed classification for determination of seam inclination

Seam inclination (◦)	45-70	30-45	15-30	5-15	0-5
	Very high	High	Medium	Low	Very low

2.2. Seam thickness

The thickness of the seam and its regularity is an important determinant of the level of mechanization that could be applied at a typical coal face. Supports can be lengthened and further increased by some additions. However, great irregularities cannot be accommodated. Cutting low sections may be difficult for the winning machines and washing facilities. Therefore, a good survey of the seam should be made before choosing proper support. The thickness that can be worked, at present, ranges from 0.6 to 5 m with most seams between 1 and 3 m. In seams thicker than 3 m or thinner than 0.6 m, the possibility of mechanization will be reduced. Thicker seams should be worked out in slices or by recovering the caved coal from the back by special arrangements. The proposed classification for evaluating of seam thickness is given in Table 2.

TABLE 2

Proposed classification for determination of seam thickness

Seam thickness (m)	0.6-1.0	1.0-1.4	1.4-2.4	2.4-4.5	4.5-6
	Very narrow	narrow	medium	Thick	Very thick

2.3. Geological disturbances

The effect of faulting on the geomechanics of long walls is one of the most difficult issues to predict. In some cases, the presence of faults or jointing can have a dominant effect on the geomechanics of a retreating long wall. If there are complex geological conditions such as faults and seam pinch-outs, the possibility of mechanization will be reduced. The amount of coal seam displacement and the number of faults present over the length of a seam are very important factors that affect the condition of the working face and the decision to mechanize the operation of the seam. In our study, we have defined the displacement index (I_t), a parameter, to quantify geological disturbances as follows:

$$I_t = \frac{t}{m} \tag{1}$$

Where t is the displacement of a seam by faults (m) and m is the thickness of the seam (m). Table 3 shows the level of seam uniformity with respect to the index of displacement. In this classification, seam uniformity ranges from 0 to 1, where seams with an index $I_t = 0$ are completely uniform and seams with a displacement index of more than 3, are considered to be non-uniform. The proposed classification for evaluating of seam uniformity is given in Table 3.

TABLE 3

Proposed classification for determination of seam uniformity

Seam uniformity Condition (I_m)	2.25-3.0	1.5-2.25	1.0-1.5	0.5-1.0	0-0.5
	Very low uniform	Low uniform	Semi uniform	High uniform	Very high uniform

2.4. Roof conditions

Roofs should cave. If a roof does not cave or hangs, it is not suitable for long wall mining because it may fall unexpectedly. Thus, some stowing system should be used. The most suitable roofs cave in as the support advances. However, when a very weak roof crumbles rather than holds, part of the coal seam is left to support it. Both operational experience and research results have demonstrated that roof stability is relative. For an unstable roof, certain techniques are required to control and change the factors contributing to the unstable conditions and to upgrade its stability. For a medium stable roof, a power support is required, properly selected and applied, to maintain roof stability. Often a medium stable roof becomes unstable due to periodic weighing, poor roof conditions or improperly selected power supports. For stable roofs, with the exception of a gradually sagging roof, their stability must be destroyed artificially and systematically in order to avoid large aerial caving. Other quantitative methods are available for evaluating the propensity of roofs to cave in. These methods employ various factors such as litho logical sequences, amount of roof convergence at the gob edge, lack of support over a certain time period before caving, seismic wave velocity, drill core strength, average frequency of bedding plane and rock strength and bed separation resistance. Unrug and Szwilski (1982) made recommendations concerning the principal strata control parameters for the design of long wall faces. Their empirical formula for determining the roof strength index is given as (Unrug & Szwilski, 1982):

$$Q_r = 0.016 \times \sigma_c \times K_1 \times K_2 \times K_3 \times \frac{m}{K-1} \tag{2}$$

where Q_r is the roof strength index, σ_c the average uniaxial compressive strength of the core (kg/cm^2), K_1 a factor to account for a decrease in strength from the laboratory to a field specimen, K_2 a factor to account for a decrease in strength with creep loading, K_3 a factor to account for decrease in strength with an increase in humidity, m the thickness of the immediate roof (cm) and *K* a swelling coefficient with a value between 1.3-1.5. The various design parameters are based on a roof classification system represented by the roof strength index (Table 4). Table 5 shows the values of different factors for various types of roofs. Finally, the proposed classification for evaluating of roof strength is given in Table 6.

TABLE 4

Cave ability classification based on roof strength and time exposure (Unrug & Szwilski, 1982)

Roof type	**Roof strength index (kg/cm^2)**	**Description**
Unstable	$0 \le Q \le 18$	After exposure, roof caves in immediately or after a short delay
Low stable	$18 \le Q \le 35$	Roof very difficult to control. Full of cavities, fractures and fissures, caves in easily
Medium stable	$35 \le Q \le 60$	Caves in easily. From fractured roof with local falls to fairly good roof
Stable	$60 \le Q \le 130$	Good roof with excellent caving properties to hardly any caving
Very stable	$Q \ge 130$	Very strong and very stable. Artificial caving is necessary

TABLE 5

Values of different factors for different rocks

Rock type	**Sandstone**	**Mudstone**	**Siltstone**
K_1	0.33	0.42	0.5
K_2	0.7	0.6	0.6
K_3	0.6	0.4	0.4

TABLE 6

Proposed classification for determination of roof strength

Roof strength (kg/cm^2)	$0 \le Q \le 18$	$18 \le Q \le 35$	$35 \le Q \le 60$	$60 \le Q \le 130$	$Q \ge 130$
	Unstable	Low stable	Medium stable	Stable	Very stable

2.5. Floor conditions

The floor should be strong enough to resist intrusions. Intrusion of soft floors is troublesome for advancing and also makes the roof conditions difficult to control owing to high convergence. Some coal may be left if the coal is hard. The reaction of floors to any kind of support, installed along or behind long wall faces, significantly affects strata stability. If the design of the support is to be based on an acceptable rate of closure or deformation along a long wall face and its ends, then, in order to ensure support balance and stability, the stratum pressure within the face region should be controlled. This requires: (a) uniform pressure and deformation distribution along the face; (b) a floor bearing capacity in excess of the effective stratum pressure exerted upon it through the supports (Afrouz et al. 1988). Where footwall rocks are weak, support systems may fail by punching into the peripheral rock of ore bodies. The failure mode is analogous to bearing capacity failure of a foundation and may be analyzed as such. The floor rock bearing capacity is direct related with the uniaxial compressive strength of rocks. In general, a higher strength implies a greater bearing capacity and a greater potential for mechanization of the seam. The proposed classification for evaluating of bearing capacity is given in Table 7.

TABLE 7

Proposed classification for determination of bearing capacity

Bearing capacity (MPa)	0-30	30-50	50-70	70-90	90<
	Unstable	Low stable	Medium stable	Stable	Very stable

2.6. Water at the working face

Water at the working face is detrimental and corrosive to the supports. Under these conditions either the panel should be drained by drilling, or special anticorrosive supports should be chosen. Water is always a handicap and miners hate to work under wet conditions. The proposed classification for evaluating of water at the working face is given in Table 8.

TABLE 8

Proposed classification for determination of water at the working face

Index					
Water at the working face (m^3/min)*	150<	50-150	20-50	10-20	0-10
	Very aqueous	aqueous	Very wet	wet	dry
* m^3 per minute for each 10m of face length					

2.7. Extension of Seam

The panel should be large enough to use powered supports. It takes 15–20 days to install the equipment, which adds to the cost of the coal; the larger the panel the lower the installation cost per ton of extracted coal. However, very large panels may be expensive in upkeep of the gateways, although this is not an insurmountable problem. The optimum width is found to be 800–1000 m.

TABLE 9

Proposed classification for extension of seam

Extension of Seam (m)	200-600	600-1000	1000-2000	2000-4000	4000<
	Very small	small	medium	large	Very large

3. Development a new classification system

Until now, no comprehensive classification has been developed for evaluating the coal seam mechanization. The main objective of this paper is to present a new classification system for evaluating the effective factors on coal seam mechanizability using the analytic hierarchy process (AHP). This research considers the coal seam mechanization classification as a decision problem and applies AHP method as a tool for weighting calculations. Finally, a new classification system named "coal seam mechanization index (CSMi)" is presented and described. Analytic hierarchy process (AHP) is a multi attribute decision- making (MADM) technique that was first developed in 1980 by Thomas Saaty (Saaty, 1980). It is a tool to combine qualitative and quantitative factors in the selection of a process, and is used for setting priorities in a complex, un-anticipated, multi-criteria problematic situation. Firstly, according to AHP method the pair-wise comparison matrix was built by using Saaty's 1-9 scale. This pair-wise comparison is shown here:

$$\begin{bmatrix} & c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 \\ c_1 & 1 & 2 & 2 & 2 & 4 & 5 & 3 \\ c_2 & 1/2 & 1 & 1 & 1 & 2 & 3 & 2 \\ c_3 & 1/2 & 1 & 1 & 1 & 3 & 4 & 2 \\ c_4 & 1/2 & 1 & 1 & 1 & 3 & 3 & 2 \\ c_5 & 1/4 & 1/2 & 1/3 & 1/3 & 1 & 2 & 1/2 \\ c_6 & 1/5 & 1/3 & 1/4 & 1/3 & 1/2 & 1 & 1/3 \\ c_7 & 1/3 & 1/2 & 1/2 & 1/2 & 2 & 3 & 1 \end{bmatrix}$$

c_1: Seam inclination
c_2: Seam uniformity Condition
c_3: Seam thickness
c_4: Roof strength
c_5: Bearing capacity
c_6: Water at the working face
c_7: Seam Extension

Finally, the calculated weights of major parameters are shown in Table 10.

TABLE 10

The calculated weights of major parameters

Parameters	Seam inclination	Seam thickness	Roof strength	Seam uniformity Condition	Seam Extension	Bearing capacity	Water at the working face
Weight	0.29	0.18	0.17	0.16	0.1	0.06	0.04

In the new classification system, the coal seam was classified into five categories: excellent, good, fair, poor and very poor. In the new classification system to rate the various values of each parameter, the most weights have been rated for the excellent mode. Rates of good, fair, poor and very poor determined, respectively, 70%, 50%, 25% and 10% of excellent mode. By order of above rating, the classification system becomes non-linear (Hoseinie et al., 2008, 2009; Mikaeil et al., 2011). Considering relative importance of the various parameters utilized for assessment of coal seam mechanization index, it has been assumed that the total rate is 100 as a maximum, which represents the best conditions of mechanization. The coal seam mechanization classification and is given in Table 11. Moreover, one user can classify and qualitatively predict the mechanizability of coal seam with use of Table 12.

TABLE 11

Coal seam mechanization classification

Seam inclination	45-70	30-45	15-30	5-15	0-5
Score	**2.9**	**7.25**	**14.5**	**20.3**	**29**
Seam thickness	0.6-1.0	1.0-1.4	1.4-2.4	2.4-4.5	4.5-6
	Very narrow	narrow	medium	Thick	Very thick
Score	**1.8**	**4.5**	**9**	**12.6**	**18**
Seam uniformity condition	2.25-3.0	1.5-2.25	1.0-1.5	0.5-1.0	0-0.5
	Very low uniform	Low uniform	Semi uniform	High uniform	Very high uniform
Score	**1.6**	**4**	**8**	**11.2**	**16**
Roof strength	>130	0-18	18-35	35-60	60-130
	Unstable	Low stable	Medium stable	Stable	Very stable
Score	**1.7**	**4.25**	**8.5**	**11.9**	**17**
Bearing capacity	0-30	30-50	50-70	70-90	90<
	Unstable	Low stable	Medium stable	Stable	Very stable
Score	**0.6**	**1.5**	**3**	**4.2**	**6**
Water at the working face	150<	50-150	20-50	10-20	0-10
	Aqueous			wet	dry
Score	**0.4**	**1**	**2**	**2.8**	**4**
Extension of seam	200-600	600-1000	1000-2000	2000-4000	4000<
	Very small	small	medium	large	Very large
Score	**1**	**2.5**	**5**	**7**	**10**

TABLE 12

Prediction of coal seam mechanization using CSMi

CSMi	10-20	20-40	40-60	60-80	80-100
Description	Very low	Low	Medium	High	Very high
Mechanizability	Very poor	Poor	Medium	Good	Very good

4. Case study

The Eastern Alborz coal basin is located in northern Iran and presently includes all the carboniferous sediments contained within the bounderieas formed by the Firoozkooh road and the Bojnord-Esfarayen road (Doulati Ardejani et al., 2008). Our exploration studies also include the carboniferous sediments in the margin of the central desert in Iran such as the Chahshirin-Jam and Larestan and on the east side our study area continued to the Sarakhs. The Takht coal mine is one of a number of mines in the Eastern Alborz coal basin, situated to the south east of Minoodasht city in Golestan Province (Iran). In this study, the potential for mechanization of the Takht coal seams were investigated by using the new classification system. Table 13 shows the result of this study of the potential for mechanization of these coal seams. The results show that the 4 seams of total studied seam was high potential and 2 seams was medium potential for mechanization of the Takht coal seams. Totally, it is obvious that the 67 percent of total Takht seams have a good condition for mechanization.

TABLE 13

Potential for Mechanization of the Takht coal seams

Seam	Seam Inclination (°)	Seam Thickness (m)	Seam uniformity	Roof Strength (kg/cm^2)	Bearing capacity (MPa)	Water at the working face (m^3/min)	Extension of seam (m)	Potential for Mechanization	
								Score	Q_i
K8	32.5	1.1	0.25	140.4	112.5	5	6500	49.45	Medium
K10	30	1.6	0.25	226	112.5	6	10580	61.2	High
K11	26	1.2	0.25	417.7	83.4	4	7000	54.9	Medium
K17	30	0.9	0.25	128	258.7	5	3500	66.3	High
K19	30	1.6	0.25	219.6	258.7	3	4500	61.2	High
K20	29	0.6	0.25	65.3	112.5	5	5250	69.3	High

5. Conclusions

The most important objectives of mechanization are follows: reduced costs; faster development; faster mining; safer mining; concentrating production at fewer locations; achieving higher production rates per shift; mining with smaller underground crews; smaller capital expenditure per extracted ton of coal; work under protectively supported roofs; development of more productive crews. Coal has always been considered an important source of energy and despite short-term fluctuations; its long-term total demand in the world shows an upward trend. Reducing costs, achieving higher production rates per shift and increasing safety levels are the most important problems in Iranian coal mines. Therefore mine mechanization is required. Mine mechanization needs large amounts of investments and should therefore be studied carefully before final decisions on the implementation of mechanization. In this study, the most important parameters affecting the feasibility of using mechanized mining of coal seams have been presented in terms of seam gradient and thickness, geological disturbances, seam floor conditions, roof formation and water at the working face. In our study, a new classification system has been developed based on analytic hierarchy process (AHP) technique and by using the seam gradient and thickness, geological disturbances, seam floor conditions, roof formation and water at the working face. The potential for coal seam mechanization can be evaluated by using this classification system with use of a new index named coal seam mechanization index (CSMi). Potential mechanization of the Takht coal mines in Iran was investigated as a case study. The results showed that the 67 percent of total studied seam was high potential and 33 percent was medium potential for mechanization of the Takht coal seams.

Acknowledgment

The authors would like to thank the Islamic Azad University, Shahrood Branch, Shahrood, Iran for providing the facilities in order to perform an original research.

References

Afrouz A., Hassani F., Scoble M.J., 1988. *Geotechnical assessment of the bearing capacity of coal mine floors*. International Journal of Mining and Geological Engineering, (6), p. 297-312.

Ataei M., Khalokakaei R., Hossieni M., 2009. *Determination of coal mine mechanization using fuzzy logic*. Mining Science and Technology, 19, p. 0149-0154.

Doulati Ardejani F., Jodieri Shokri B., Moradzadeh A., Soleimani E., Ansari Jafari M., 2008. *A combined mathematical–geophysical model for prediction of pyrite oxidation and pollutant leaching associated with a coal washing waste dump*. International Journal of Environmental Sciences & Techniques, 5(4), p. 517-526.

Hoseinie S.H., Aghababaei H., Pourrahimian Y., 2008. *Development of a new classification system for assessing of rock mass drillability index (RDi)*. Int. J. Rock Mech. Min. Sci.; 45(1): p. 1-10.

Hoseinie S.H., Ataei M., Osanloo M., 2009. *A new classification system for evaluating rock penetrability*. International Journal of Rock Mechanics & Mining Sciences.; 46: p. 1329-1340.

Mikaeil R., Yousefi R., Ataei M., Abasian Farani R., 2011. *Development of a New Classification System for Assessing of Carbonate Rock Sawability*, Archives of Mining Sciences, Vol. 56, No 1, p. 57-68.

Unrug K., Szwilski B., 1982. *Methods of roof cavability prediction*. State of the Art of Ground Control in Long wall Mining and Mining Subsidence, AIME, p. 13-29.

Saaty T.L., 1980. *The analytic hierarchy process*. New York: McGraw-Hill.

Received: 25 January 2012