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Assessment of roof convergence during driving roadways in underground coal mines by continuous miner

Prabhat Kumar Mandal[a,*], Arka Jyoti Das[a], Nirmal Kumar[b], Rana Bhattacharjee[a], Subhashish Tewari[a], Angad Kushwaha[a]

[a] *CSIR-Central Institute of Mining and Fuel Research, Barwa Road, Dhanbad, 826015, India*
[b] *South Eastern Coalfields Limited, Seepat Road, Bilaspur, 495006, India*

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ABSTRACT

In India, a number of coal seams are being extracted by using the continuous miner (CM). There is a need to standardise some of the major parameters like cut-out distance (COD) and the convergence of the roof strata for safe operation of the CM. The production and productivity of this system mainly depend on the COD, i.e. the length of the stable drivage made in the coal seam by the CM at a time without installing any reinforcement/support. This factor is determined by assessing the convergence of the roof strata. Therefore, prior to driving of the roadways by the CM, the estimation of the convergence of the roof strata is necessary for safe and stable driving of the roadways. No suitable empirical relationship is found between the convergence and the COD. This paper deals with the assessment of the roof convergence during development of the coal seams by the CM. Variations of the convergence with the major influencing parameters, i.e. the COD, the rock mass rating and the width of the gallery, are obtained by the parametric study through elasto-plastic numerical modelling. The trend of the convergence data with respect to the input parameters is found non-linear. Thus, a non-linear multivariate model is framed by putting the constant and exponents in the input parameters. These constant and exponents are determined through regression analysis to develop a predictive model. The coefficient of determination of the model is around 0.98. The model is validated with the monitoring data of different mines. This model can be applied for the assessment of the convergence of the roof in underground coal mines for safe driving of the roadways by the CM. Alternatively, optimum COD of the CM can be designed by fixing the threshold limit of the convergence value for a particular geomining condition.

1. Introduction

Suitable mass production technologies are required to overcome the low production and productivity problems of the underground mining in India and make it economically viable.[1,2] Large-scale mechanisation of the underground coal mines is the option to increase the production, productivity and safety.[3] Continuous miner (CM) technology based mechanisation has brought enormous hope for the underground coal mining industry in India. Application of CM technology has proven its potential for the exploitation of the coal seams in Indian geomining conditions.[4–7] CM based mechanisation is getting preference by the coal mining industries in India mainly due to its easy adaptability in the Indian geomining conditions and a moderate level of investment with comparatively higher production and productivity. Due to its characteristics of fast and safe extraction,[8,9] a number of coal seams are being developed and depillared by using the CM. A number of proposals are also in the pipeline to introduce the CM in Indian underground coal mines. It is also getting preference by the mining community due to its better strata management[2,4,10] than the conventional extraction of coal seams by drilling and blasting method.

Considering the large-scale application of the CM in underground coal mines, there is a need to study and standardise some of the important parameters to facilitate safe and productive operation of the CM. Cut-out distance (COD) and amount of convergence of the roof strata are the two important interrelated parameters. There is a need to establish an easy relationship between these two important parameters which can be used as a handy tool by the practising mining engineers during CM operation. The rate of production of the coal by the CM system depends on how much coal can be cut at a time without installing any support,[11] i.e. the amount of coal available at one place for cutting operation. Higher the amount of coal available for cutting at one place, higher will be the output of the system. The length of the

* Corresponding author.
E-mail address: pkmandal@cimfr.nic.in (P.K. Mandal).

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stable drivage, that can be cut at a time in one place by the CM without installing any support, is termed as COD.[5,12–14] The COD has a direct impact on the production and productivity of the CM technology for a particular geomining condition. The amount of coal to be available at one place for cutting operation mainly depends on the dimension of the gallery or drivage besides the distance to how far can the CM goes safely beyond the last line of support system. Higher COD enables the CM to cut more coal continuously. Hence, the role of COD can be a decisive factor for the success of any continuous mining operation. With the increase of the COD, the production and the productivity also increase as it decreases the frequency of shifting of machines. Considering the importance of COD in the CM operated underground coal mines, there is a need to determine this important parameter for the smooth operation of the CM. The literature review showed that in earlier years when CM was operated by an on-board operator, the COD was limited to 6.0 m, i.e. the distance between the cutter head and the operator's compartment, as regulations or guidelines do not allow anybody to go under unsupported roof. But, the standard COD values with a remote-controlled CM are 7.8 m in the UK, 14 m in Australia, 19.5 m in USA and 12 m in South Africa.[15] The permissible COD in different countries is decided mainly by considering human and ventilation issues rather than roof instability.[15] Molinda and Mark[16] proposed the Coal Mine Roof Rating (CMRR) for US coal seams in order to identify the lithological factors that influence the structural competence of a mine roof. Based on CMRR value, Mark[17] predicted safe cut-out values for US coal mines. Bauer[14] proposed a relationship for a safe COD during pre-approval stage of a mine based on CMRR approach. Canbulat and Van der Merwe[15] used conventional gravity loaded beam theory, numerical modelling as well as instrumentation for 6 different mines in South Africa for the determination of COD under different geomining conditions. Chen et al.[18] described a method for computing unsupported roof distance in roadway advancement and its in-situ application for a particular mine in China. They found that the 6.0 m COD was safe for that particular mine. Saharan et al.[13] determined the gallery width and safe COD of 12 m for a particular mine in India. It is worth to mention here that COD is very much site-specific and should take care of all the influencing geomining conditions. A safe COD can effectively be designed based on the roof deformation study because there are limitations to increase the COD due to the instability issues of the surrounding strata, especially the roof formations.[12] The design of COD based on the roof convergence takes care of most of the site conditions.

The cutting of the coal disturbs the equilibrium of the surrounding rock mass. As the stratified rocks content very persistent bedding planes[19–21] and no support is applied immediately up to the length of the COD, the overlying strata try to separate from each other due to their own weight.[20,22–24] When the separation of the bedding planes reaches the threshold value[22,25] for a particular geomining condition, the roof falls take place in that locale. During the development of galleries by the CM, it should be ensured that the convergence of the roof should not exceed the threshold limit of failure. Therefore, prior to any extraction, there is a need to know the amount of convergence of the roof strata for a particular geomining condition. This can be done by monitoring the convergence of the overlying strata. This is required to get an idea about the possible behaviour of the roof and to set the safe limit of the convergence and the warning signals in the instruments for the development operation by the CM. To ensure the stability of the working, the estimation of the roof convergence is required for a particular COD so that this value should not exceed the threshold limit. Ghosh and Ghose[25] studied estimation of critical convergence and rock load in coal mine roadways. They measured the convergence of roof at the mines where extraction of coal was done by blasting. Vervoort[26] studied the convergence of the roof and floor in longwall faces. He developed a semivariogram model of convergence by using monitoring data. He also described the convergence with respect to the production cycle. But, his study does not deal with the convergence of roadways in bord and pillar mines. Thus, the findings of their studies have the limitation to apply in case of extraction of coal by machine, i.e. CM. There is no suitable literature found where a empirical relationship has been developed between the convergence value and the COD. Therefore, an attempt has been made in this paper to develop a predictive model which would help to predict the roof convergence for the safe extraction of the coal by the CM. Alternatively, safe COD of a CM deployed mine can be determined, using the model by fixing the threshold limit of the convergence value during the driving of the roadways in coal seams. This study is helpful to the mine planners, operators as well as practising mining professionals for efficient utilisation of the CM and to optimise the production capacity of a CM face. It would also help to optimise the support requirements during driving of the roadways in the underground coal mines.

The measurement of the roof deformation or convergence in the gallery can be done by mechanical instruments read by the human eyes, auto-recording instruments, and remote monitoring systems.[20,27] The data obtained from the monitoring helps to ensure the stability of the surrounding rock mass[28,29] for a particular geomining condition. In this study, the strata monitoring data of the convergence of the roof are generated/collected, using geotechnical instruments from the most of the mines in India, where the development of drivages of the coal seams (Fig. 1) have been done with CM deployment. Along with the generation/collection of the roof convergence data from different mines, elasto-plastic numerical modelling has been carried out in this study by using FLAC3D (Fast Lagrangian Analysis of Continua in 3 dimensions)[30] to assess the convergence value of the roof for various geomining conditions. The data and parameters used for the parametric study are calibrated with the field conditions. Based on the simulation data, a predictive model has been developed for assessment of the convergence of the roof strata by multivariate non-linear regression (MNLR) technique.[31] The validation of the predictive model to determine the convergence value for the safe COD is carried out by the measured field monitoring data of the available underground coal mines where drivages were made by using the CM. This model can be used to determine the safe COD of the CM during the driving the roadways in coal seams.

2. Numerical modelling

An ability to provide a prior assessment of the performance of a mining structure under varying geomining conditions of the site makes a numerical modelling technique popular. Numerical modelling technique is now widely being used for understanding and solving different geotechnical problems.[32–34] It provides an ideal platform for parametric study in order to deal with a challenging geotechnical design. It is difficult to experiment with different ideas in actual field conditions because any such idea related to rock mechanics investigation carries considerable risk, and also involves a large amount of time and money. Varying geomining conditions of a mine site make such experimentation even more difficult. In fact, a numerical modelling method is an effective approach for the study of the influence of different

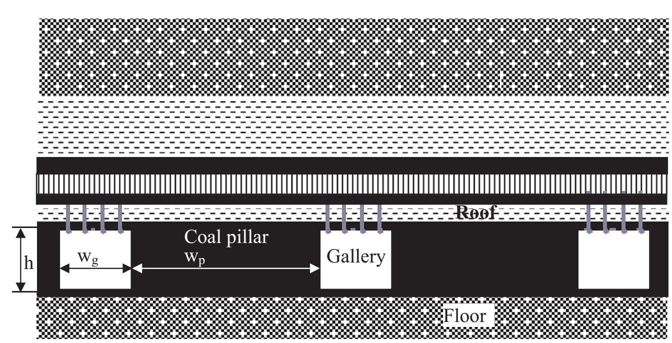

Fig. 1. Cross-sectional view of development of a coal seam where h is the height of working; w_p is the width of coal pillar and w_g is the width of gallery.