Journal of Scientific & Industrial Research
Vol. 68, April 2009, pp. 307-311

Proposed hybrid method of partial extraction

Ashok Jaiswal and B K Shrivastva*
Department of Mining Engineering, Institute of Technology, Banaras Hindu University, Varanasi 221 005, India

Received 27 June 2008; revised 20 January 2009; accepted 27 January 2009

This paper introduces a hybrid method of partial extraction by combining widely used methods, wide stall method for big pillar and pillar splitting method for small pillar. Stability criteria for proposed method ensures stability and non-violent failure condition of pillar. Numerical simulation of underground coalmine was carried out by finite element method (FEM) and boundary element method (BEM). Coal pillars were simulated by FEM to determine stress-strain behaviour. Coal panel was simulated by BEM to determine local mine stiffness and superimposed load on simulated coal pillars.

Keywords: BEM, FEM, Hybrid method of partial extraction, Pillar splitting method, Wide stall method.

Introduction

Bord and Pillar system of mining is widely used for coal extraction. Partial extraction method is generally adopted for maximum possible extraction of coal without damaging the surface. Optimum coal extraction from coal panel must be carried out in such a way that remained coal is minimum with all stability requirement of pillar and roof. Coal pillars are designed based on site-specific empirical formulas[1-5], requiring considerable higher factor of safety (FOS), which in turn reduces coal recovery. Probability of coal pillar failure can be reduced with increasing FOS. Minimum FOS (2) of pillar is widely accepted in Bord and Pillar system of mining[6].

This paper proposes a hybrid method of partial extraction by combining wide stall method used for bigger pillar and pillar splitting method used for smaller pillar.

Proposed Hybrid Method of Partial Extraction

Classical approach of partial coal extraction is to design all coal pillars of identical shape and size (FOS >2). For pillars (FOS < 1.5) left out to enhance coal recovery, failure of a pillar may induce chain reaction of pillar failure, which could be restricted by having some bigger pillars within panel. Hybrid method of partial extraction has been introduced for achieving higher coal recovery as compared to conventional partial extraction methods. It is a combination of smaller and bigger pillars in chessboard pattern (Fig. 1). Sequence of partial extraction of simulated coal panel could be done in two stages: i) Formation of wide stall pillar by extracting a slice in 'L' shape from its sides; and ii) Alternate pillars in chessboard pattern may further split into two stooks.

Methodology for Stability Analysis

For long-term stability, FOS of smaller pillars (split pillars) of proposed method should be >1. If any of smaller pillars fails, bigger pillars may restrict chain reaction of pillars failure depending upon nature of pillar failure[7], which will decide stability of a simulated coal panel. Pillars may fail either in violent or non-violent way. Mode of pillar failure depends on its post-failure stiffness (k_C) and local mine stiffness (k_{LMS}) (Fig. 2). In non-violent pillar failure condition, smaller pillars do not fail completely and have some residual strength to provide overburden reaction against failure. Excess stress (pre-failure stress – residual strength) redistributes to surrounding pillars. Amount of excess stress is dependent on the nature of overburden as well as post-failure nature of coal pillar. Thus, panel stability consisting of FOS of panel and pillar are more appropriate parameters. Panel stability conditions are as follows: 1) $Pillar_{FOS}$ > 1.0 for smaller pillars, and $Pillar_{FOS}$ > 2.0 for bigger pillars; and 2) $Panel_{FOS}$ > 2.0. Ratio of k_{LMS} and k_C of coal pillar is termed as panel factor of safety[8] ($Panel_{FOS}$). First condition

*Author for correspondence
E-mail: bk_shrivastva@rediffmail.com

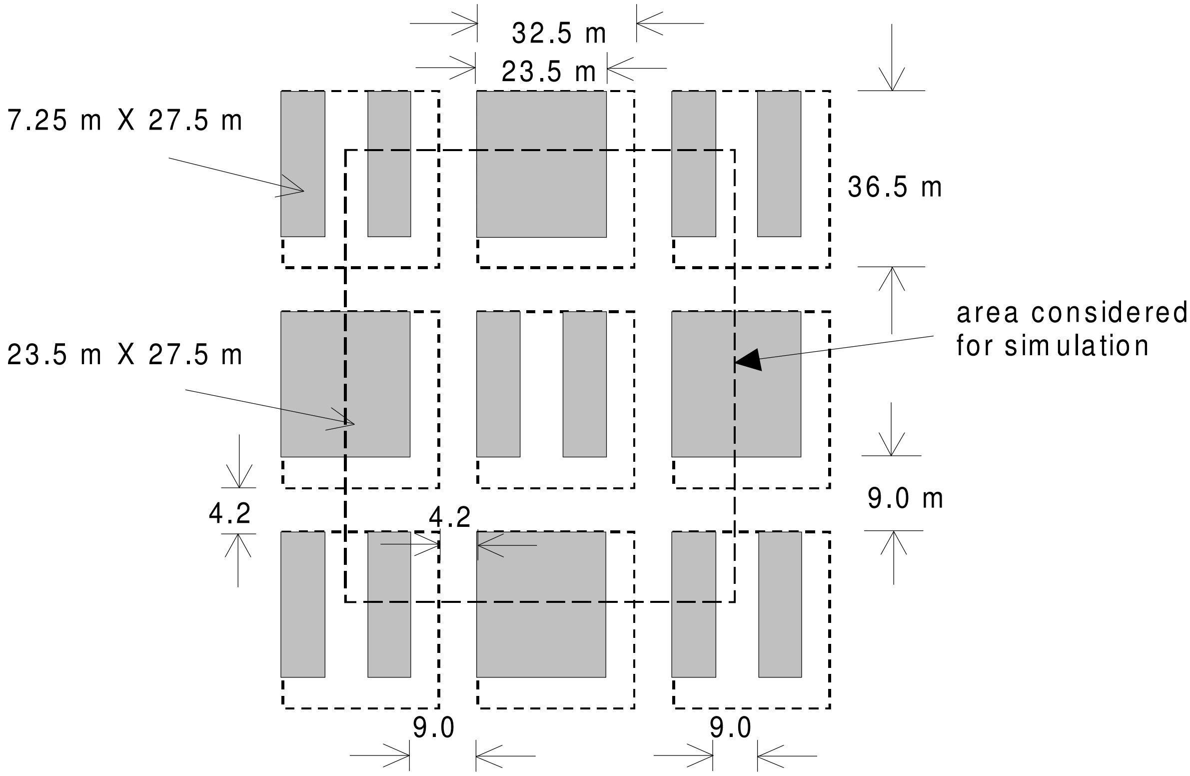

Fig. 1—Partially extracted panel simulation

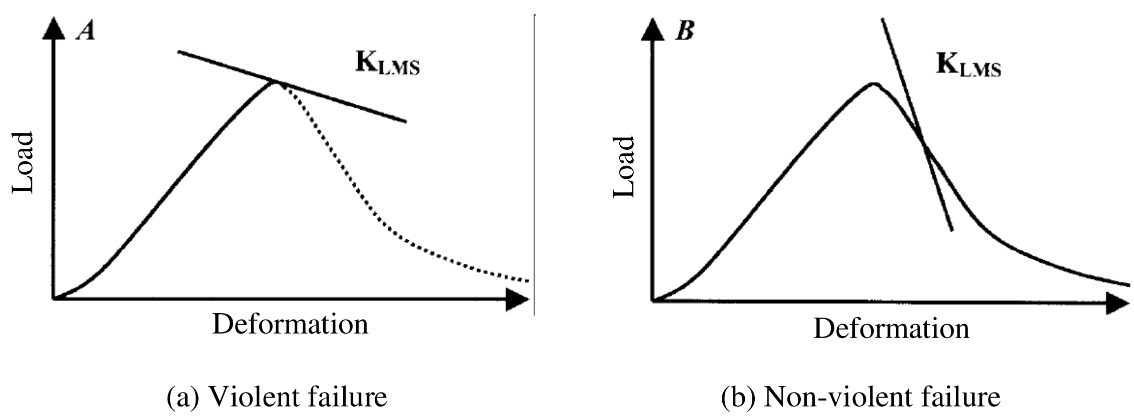

Fig. 2—Mode of pillar failure

of panel stability criteria ensures stability of pillars, whereas second condition provides confidence against panel instability.

A Case Study

Salient features of coal panel, chosen for stability analysis of proposed method, are as follows: pillar size (center to center), 32.5 m x 36.5 m; gallery width, 4.2 m; gallery height, 3.0 m; and depth, 100 - 180 m. Layout plan view of panel and bore-hole section of strata are shown in Fig. 1 and Fig. 3 respectively. Developed pillars were partially extracted by wide stall method with 9.0 m wide galleries in first stage. Dimensions of these pillars reduced to 23.5 m x 27.5 m (corner to corner). In second stage, alternate pillars in chessboard pattern were further considered to be splitted by 9.0 m

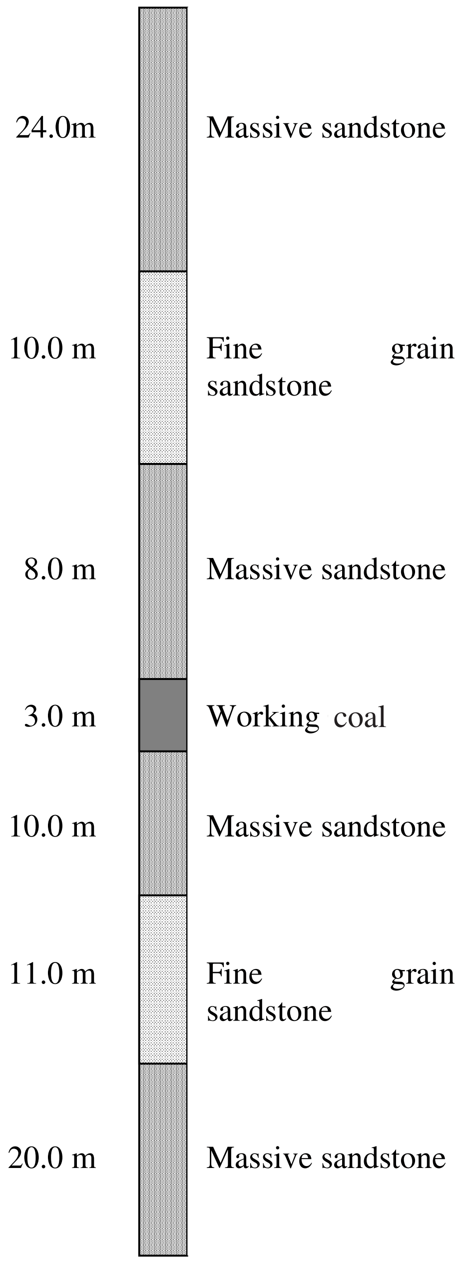

Fig. 3—Sectional view of bore-hole strata

wide galleries into two stooks (7.25 m x 27.5 m, corner to corner). Proposed method gave higher coal recovery (56%) than by conventional wide stall method (45%) with 9.0 m wide gallery. Salient features of proposed partially extracted panel are as follows: size of split pillars (X), 7.25 m x 27.5 m (corner to corner); size of wide stall pillars (Y), 23.5 m x 27.5 m (corner to corner); depth of seam, 100 - 180 m; extraction, 56%.

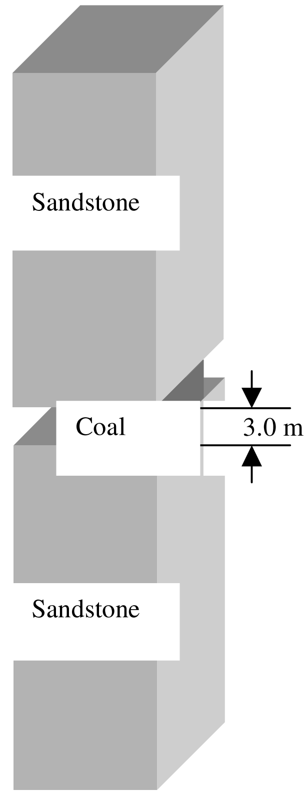

Fig. 4—Isometric view of typical quarter pillar

Numerical Simulation of Panel

Three parameters (FOS, post-failure stiffness of coal pillar section and local mine stiffness), which are involved for accessing panel stability of pillar, can be better simulated by boundary element method (BEM) than finite element method (FEM). However, FEM is best suited to simulate coal pillar for determination of its stress-strain behaviour in post-failure region. Therefore, FEM determined average axial stress-strain behaviour (or post-failure stiffness) and peak strength of individual coal pillars comprising panel. BEM simulated panel for determination of k_{LMS} and load on pillars.

Pillar Modelling

In proposed method, two different sizes of pillars comprising a panel (X and Y) have been simulated by 3D FEM for analysis of peak strength and k_C. A quarter of pillar was modeled due to symmetry in nature (Fig. 4). Height of pillar was taken 3.0 m. Bottom of model was restricted in vertical direction and sides of boundary were fixed in horizontal direction. Sandstone

Table 1—Results of BEM modelling at 100.0 m depth

STAGE I		STAGE II		$k_{LMS} = \frac{f_1}{d_2 - d_1}$ (GN/m)
Load on split pillar section (f_1)	Load on bigger pillar	convergence at split pillar section (d_1)	convergence at split pillar section (d_2)	
2.45 GN	3.48 GN	0.00913 m	0.01835 m	265.7

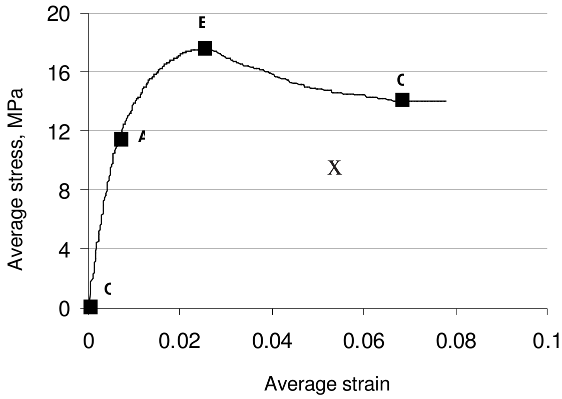

Fig. 5—Stress-strain behaviour of coal pillar (7.25 m X 27.5 m)

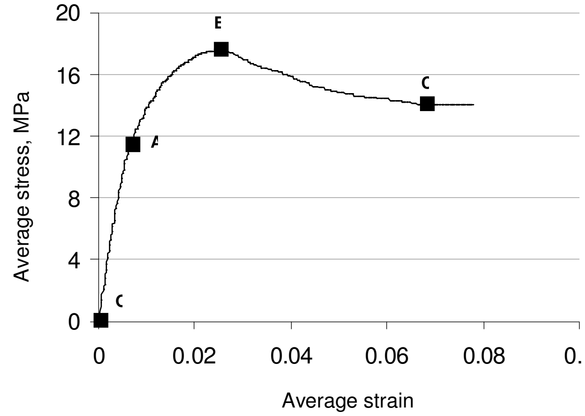

Fig. 6—Stress-strain behaviour of coal pillar (23.5 m X 27.5 m)

layers were considered in elastic domain as linearly elastic material and modeled as continuum. Hoek-Brown failure criterion with strain softening material was considered in simulation[9]. Material properties of sandstone (rock mass) and coal were as follows, respectively: Young's modulus, 9.8, 2.0 GPa; and Poisson's ratio, 0.2, 0.25. Uniaxial compressive strength of coal was 45.0 Mpa. Hoek-Brown strain softening parameters were: m_i, 1.47; s_i, 0.01; m_r, 0.125; s_r, 0.000001; α, 75; and critical plastic strain $\gamma^{p,*}$, 0.002. A constant initial displacement was given in incremental nature at top of the model. Model was solved at each increment of initial displacement (strain = displacement / height) and corresponding average axial stress was determined and plotted to determine peak strength and post-failure behaviour.

Local Mine Stiffness (k_{LMS})

k_{LMS} depends on deformation rate of rock mass (due to changes in force acting on rock mass) and mine geometry. Since smaller pillar is most likely to fail, therefore, all calculations were based on smaller pillar of the panel. Section of proposed panel (hatched, Fig. 1) was simulated by taking advantage of symmetry of pillar array. All four sides of model were fixed in horizontal direction. Depth of seam was taken 100.0 m. LMS was calculated in two steps: i) Determination of average force, F_{avg} (average vertical stress on pillar multiplied by cross-sectional area of pillar); and ii) Determination of average deformation, U_{avg} [or difference of convergence with (d_1) and without (d_2) of centre pillar]. k_{LMS} was determined as a ratio of F_{avg} to U_{avg}; $k_{LMS} = F_{avg}/U_{avg}$. k_{LMS} of proposed panel has been estimated by BEM (Table 1).

Panel Factor of Safety

Post-failure stiffness of remnant portion of central pillar was computed as

$$k_C = (A)(E_{post}) / h \qquad \ldots(1)$$

where, A, total c/s area of remnant portion of central pillar; k_C, post-failure stiffness of remnant portion of central pillar; E_{post}, post-failure modulus of a pillar or stook; and h, height of pillar.

Table 2—Analysis for panel stability

Depth	Av. stress		FOS_{split}	$FOS_{wide\ stall}$	$Panel_{FOS}$
	split pillar	wide stall pillar			(k_{LMS} / k_C)
100.0 m	6.15 MPa	5.38 MPa	1.59	3.27	4.9
155.0 m	9.53 MPa	8.33 MPa	1.02	2.11	4.9

Results and Discussion

Pillar Behaviour

Average stress-strain behaviour of split pillars of X (Fig. 5) and Y (Fig. 6) depicted that pillar behaves elastically from point O to A. Point A represents 2/3 of peak strength. In A-B region, strain hardening of pillar is observed. Point B represents peak strength of pillar. Pillar comes in softening region in B-C zone. Tangent on stress-strain curve immediately after peak strength is called as post-failure modulus of pillar. Results of pillars X and Y are as follows, respectively: peak strength, 9.8, 17.6 Mpa; E_{post}, 405.2, 112.6 Mpa; and k_C (remnant portion of central pillar), 53.8 GN/m, not required in analysis.

Analysis of Panel Stability

Stability of proposed panel at different depth levels have been analyzed based on the results of numerical modelling (FEM and BEM) as per proposed methodology under following conditions: a) all small pillars must have FOS >1 whereas, FOS of bigger pillar must be > 2.0; b) $Panel_{FOS}$ should be >2.0. Analysis has been made in terms of FOS of bigger and smaller pillars at 100.0 m depth. Parameters k_C, strength of pillar and k_{LMS} are almost independent of depth, while stress on pillar is linearly dependent on depth. Thus, FOS of pillars has been interpreted at different depth level (Table 2). FOS of split pillar at depth of 155.0 m is marginally above one. Thus, limiting depth of design under stable panel consideration is up to 155.0 m. FOS of bigger pillars are > 2.0 at 155.0 m depth for 9.0 m wide galley.

Conclusions

Proposed hybrid method of partial extraction of coalmine gives better recovery of coal without compromising stability of underground as well as surface structures. Concept of panel FOS has been proposed along with pillar FOS for predicting stability of underground coal structures. It is a two fold system: i) small pillars in a panel must have FOS >1 with FOS >2 for bigger pillars; and ii) FOS for panel must be > 2. Analysis of a case study of underground coalmine indicated that higher coal recovery was achieved by proposed hybrid method.

References

1 Holland C T & Gaddy F L, The strength of coal in mine pillars, in *Proc 6th US Symp on Rock Mechanics* (University of Missouri, Rolla, MO) 1964, 450-466.

2 Obert L & Duvall W I, Rock Mechanics and the Design of Structures in Rock (Wiley, New York, NY) 1967, 542-545.

3 Salamon M D G & Munro A H, A study of the strength of coal pillars, *J S Afr Inst Min Metall*, **68** (1967) 55-67.

4 Bieniawski Z T, The effects of specimen size on the compressive strength of coal, *Int J Rock Mech Min Sci*, **5** (1968) 325-335.

5 Sheorey P R, Pillar strength considering in situ stresses, in *Proc Workshop on Coal Pillar Mechanics and Design, USBM IC 9315*, edited by A T Iannacchione *et al* (Santa Fe) 1992, 122-127.

6 Singh R & Singh T N, Wide stall mining for optimal recovery of coal from a thick seam under surface features, *Int J Rock Mech Min Sci*, **36** (1999) 155-168.

7 Salamon M D G, Stability, instability, and design of pillar workings, *Int J Rock Mech Min Sci*, **7** (1970) 613-631.

8 Adhikary D P & Shen B, Duncan Fama, A study of highwall mining panel stability, *Int J Rock Mech Min Sci*, **7** (2002) 643-659.

9 Jaiswal A & Shrivastva B K, Numerical simulation of coal pillar strength, *Int J Rock Mech Min Sci*, accepted 23 Dec 2008, available online.