Multiseam Longwall Mining: A Parametric Study Using Finite Element Method

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Abstract

Depleting mineral reserves together with steep rise in oil prices necessitate the exploitation of deep seated coal deposits. Occurrence of multiple seams is a common feature in Indian coal mining projects. Interaction effects of multi-seam mining pose many challenges during the design and extraction of workings. A parametric study based on finite element analysis of influence of already extracted top seam on lower seam workings is presented in this paper. Results indicated that lower seam experienced maximum stress in areas lying within 10m from the barrier edge away from the goaf in top seam. There is a decrease in stress transferred over the lower seam as the thickness of parting increases.

Introduction

Large scale extraction of underground coal during longwall poses several ground control problems in the form of strata deformation and displacement, like caving, fracturing, subsidence, and floor heaving (Hasley, 1951). Knowledge of development of stresses, their magnitude and redistribution with face retreat becomes important in that respect. The stress distribution in longwall workings depends upon stiffness of coal seam, characteristics of support, seam depth, properties of the roof and floor strata, lateral extent of mining, compaction properties of broken material in the goaf, etc. In the case of typical geological formations, although the gravitational potential energy is dissipated by displacement of the roof strata in the goaf, the stress from the overburden is transferred on to the coal block and barrier (Brady and Brown, 1992). Coal seams usually occur in number of layers separated by a different type of rock mass (partings). Longwall barriers transfer higher abutment stresses to the floor and the interaction effects from longwall operations extend over far greater distances than those for bord-and-pillar mining operations. Hence, multi seam effects of longwall extraction need to be considered during the planning and design of workings. Disturbance of the *in situ* stress field caused by earlier workings in a seam will affect subsequent operations in seams both above and below the worked out seam (Hill, 1994). This interaction effect often triggers safety problems, increases cost of production, and lowers the operational efficiency and recovery of reserves (Luo, 1997; Zhou and Haycocks, 1986). Prediction of the magnitude and distribution of stress transfer between longwalls during multiple seam mining was first attempted using laminated gravity-loaded models (Forrest et al., 1988). Haycocks et al. (1982) listed four major classes of ground control problems like transfer of large concentrated vertical stresses to the workings below, arching, subsidence and inter-seam fracture that can develop as a result of multi seam mining.

Ehgartner (1982) studied the effects of minor and major arching, leading to an improved understanding of the arching mechanism using finite element stress vector plots under multiple seam conditions. The models showed that minor pressure arches in adjacent seams can interact when openings are narrow and the two seams are in close proximity, resulting in abnormally high lateral

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and abutment stresses. In longwall mining, major pressure arch formation is likely to create points of excessive stress in both overlying and underlying seams. Therefore, minor pressure arches are more applicable in describing interactions between narrow entries in close proximity, whereas major pressure arches describe the larger interactive distances associated with wide and deep openings. Recommendations have been made for longwall layout design in a multiple seam environment considering changes in pillar dimension (Scurfield, 1970). Whittaker and Pye (1975) proposed an alternate design to protect lower seam workings utilizing the de-stressed zone. Peng and Chandra (1980) suggested extracting multiple seams in descending order. If simultaneous extraction of several seams is necessary, face of the upper seam should be kept ahead of the next lower seam such that it is out of the angle of draw. Studies conducted by Sastry et al. (2007) revealed marginal increase in horizontal and shear stress as longwall face passes above goaf to the virgin area present in lower seam. A clear influence of the presence of solid coal, galleries and goaf in lower seam was found in the loading of longwall panel in upper seam. Barko (1982) studied the parting shear mechanism using both brittle physical models and finite element models. It was found that increase in Young's modulus of the parting tends to increase the chance of fracturing through parting. The cohesion and angle of internal friction seem to have little influence on the shear failure of the parting. The numerical modeling technique, MULSIM, was used to determine a stress transfer factor for undermining (Chekan and Listak, 1993). However, predicted stress transfers were found to be far below than those experienced in many field situations due to design limitations. Studies by Webster (1983) and Wu (1987) indicated that interaction effects diminish with time as time delay also allows for caving and compacting of the gob, which lessens damage to overlying gate roads upon development. Furthermore, Haycocks and Zhou (1990) classified multiseam interactions into three possible categories based on the time factor:

1. Lower seam mining and upper seam mining both are in progress. This condition was considered to be an active condition.
2. Mining in the lower seam is completed but the ground is still in the process of settling. This condition was found to be both an active and passive.
3. Subsidence is complete and the ground has settled into a new state of equilibrium which is termed as passive condition.

Hsiung and Peng (1987) conducted a study to define the influence zone for a remnant pillar and concluded that in case of a wider pillar, load would be transferred to a farther distance along the depth but the magnitude would be less than that for a narrow pillar. Maleki et al. (1985) studied the use of yield pillars in longwall gate roads in controlling interactions between two seams at a western mine in United States. He found that no three-entry system that utilized yield pillars or a combination of yield pillars and stiff pillars would satisfactorily stabilize the gate roads in both seams. Mark *et al.* (2007) established an equation that predicts the critical thickness of the parting required to minimize the likelihood of a multiple-seam interaction. The study also found that weaker roof significantly increases the risk of multiple-seam interactions. Some factors that were not found to be statistically significant included the strength of parting, time lag between mining the two seams, lower coal seam to parting thickness ratio and angle between the active mining and the remnant structure.

This paper deals with the study of interaction effects of extracted top seam workings on the lower seam longwall workings. Finite element analysis was used to evaluate the stress redistribution in lower seam due to the presence of barriers and goaf in upper seam. A parametric study was conducted by varying

the parting thickness between the top and lower seam along with the depth of top seam from the surface. Vertical stress distribution was obtained on the lower seam from the finite element analysis.

Finite Element Modeling

Three dimensional finite element models were prepared in Numerically Integrated elements for System Analysis (NISA) software. The entire rock mass was modeled using hexahedron elements. The coal seam was modeled between roof and floor strata. Properties of roof and floor strata were incorporated into the model depending on rock type and physico-mechanical properties of coal measure rocks (Table 1). The entire face width of 150m longwall panel was modeled along with barriers on both the side. The model extended up to 350m in width, 100m in length with varying depths based on the parametric study. The minimum overburden of 50m above top seam was considered for all the models. The boundary elements were modeled as roller supports. The top seam conditions like barriers, openings, and goaved out areas were incorporated into the model. The Drucker-pager yield criterion was used to model the failure condition of rock mass. In the present study, the caved material in goaf was simulated by FEM, utilizing user sub routines facility in the package and goaf development model proposed by Yavuz (2004). Yavuz's equation is applicable for depths ranging from 100m to 600m, bulking factors ranging from 1.2 to 1.5 and extraction height ranging from 1m to 4m. The model was developed based on the distance required for broken rock mass to return to overburden/ virgin pressure, bulking factor, excavation height, stress-strain behaviour of caved material and strength of main and intermediate roof strata. In the model, the height of caved zone was calculated from bulking factor of broken rock mass as suggested by Peng (1986). The initial inputs of Young's modulus of caved material were obtained from the studies conducted by Papas and Mark (1993). The influence of worked out upper seam on the lower seam was studied by varying parting thickness from 9m to 90m at an interval of 9m. The depth of top seam was also varied from 50m to 500m, at 50m interval. The extraction in both the seams was simulated by longwall mining. In total, 50 models were developed in the study.

Results and Discussions

Stress distribution in lower seam was obtained at various locations both under the goaf and coal block of top seam (Fig. 1). Results in the form of ratio of increase of stress to *in situ* stress are given in Figs. 2 to 6, for different depths of top seam. Stress in lower seam, lying under the barrier in top seam, was higher as compared to the section lying under goaf. Further, stress in section of lower seam lying under goaf of top seam was found to be less than the in situ stress. This may be due to the formation of pressure arch in roof strata of top seam, which transfers overburden stress on to barrier, forming destressed zone above lower seam.

Table 1: Properties considered in the analysis

Type of strata	Young's modulus (N/m^2)	Poisson's ratio	Density (kg/cm^3)	Cohesion (N/m^2)	Angle of internal friction (degree)
Coal seam	2×10^9	0.25	1800	8×10^6	20
Roof	5×10^9	0.3	2400	20×10^6	42
Floor	5×10^9	0.3	2400	20×10^6	42
Caved material	1.5×10^5 (initial)	0.1 (initial)	varied	-	-

This effect was observed for all the depths of top seam. Vertical stress distribution in lower seam for varying parting thickness from top seam at 50m depth is given in Fig. 2. Region of lower seam lying below the edge of upper seam barrier experienced maximum vertical stress. Influence of upper seam workings on stress distribution over lower seam decreased as parting thickness increased. Lower seam, with a parting thickness of 9m, experienced maximum stress of 3.1 times higher than the in situ stress (Fig. 2). Stress in lower seam reduced significantly from 3.1 to 1.78, 1.16, 0.83 and 0.61 times the *in-situ* stress, as thickness of parting between two seams increased from 9m to 18m, 27m, 36m and 45m, respectively. Vertical stress in lower seam decreased as the distance from edge of barrier in upper seam increased. Results indicated that the influence of barrier in upper seam was considerable on the stress distribution in lower seam up to a distance of 20m from the edge. Stress in section of seam lying 9m (parting thickness) below the upper seam goaf was found to be 0.87 times lower than the in situ stress. Section of lower seam lying 90m under the goaf of top seam experienced minimal stress of 0.31 times less than that of virgin stress. Results for other locations of top seam, i.e. 100m, 150m,

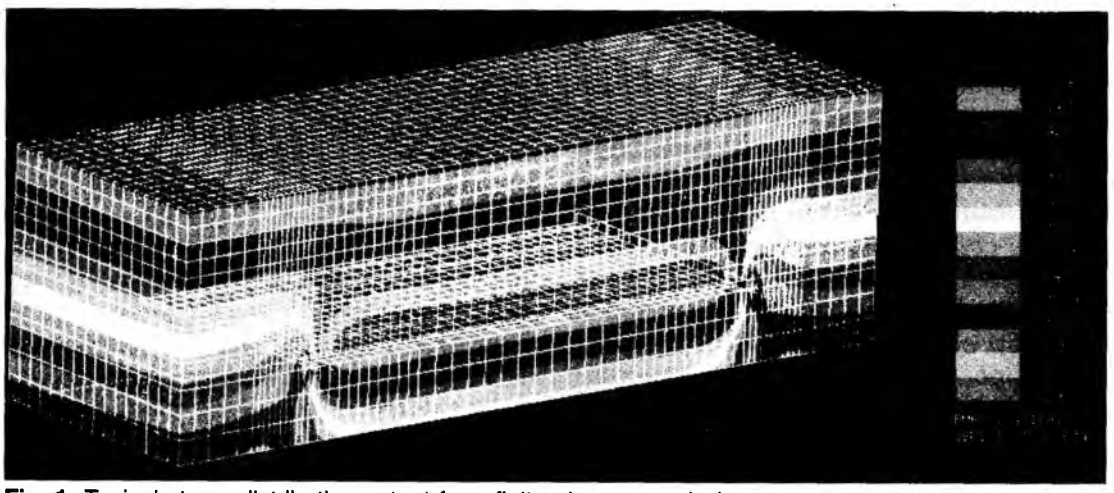

Fig. 1: Typical stress distribution output from finite element analysis

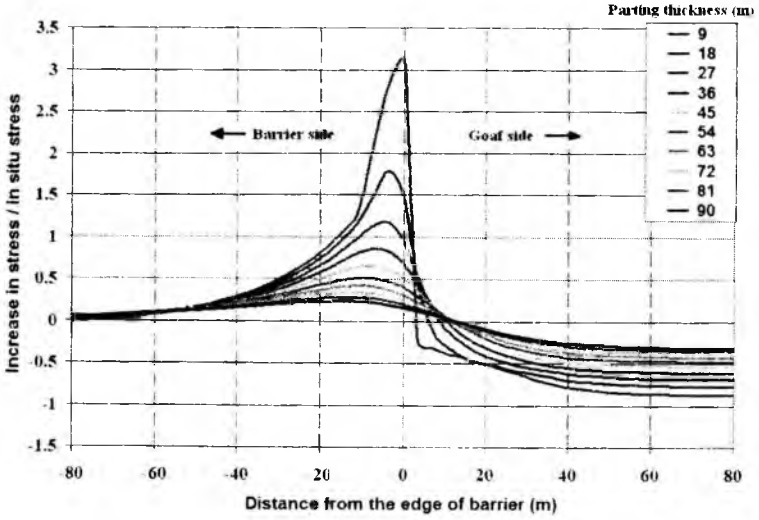

Fig. 2: Variation of stress in lower seam with top seam at 50m depth

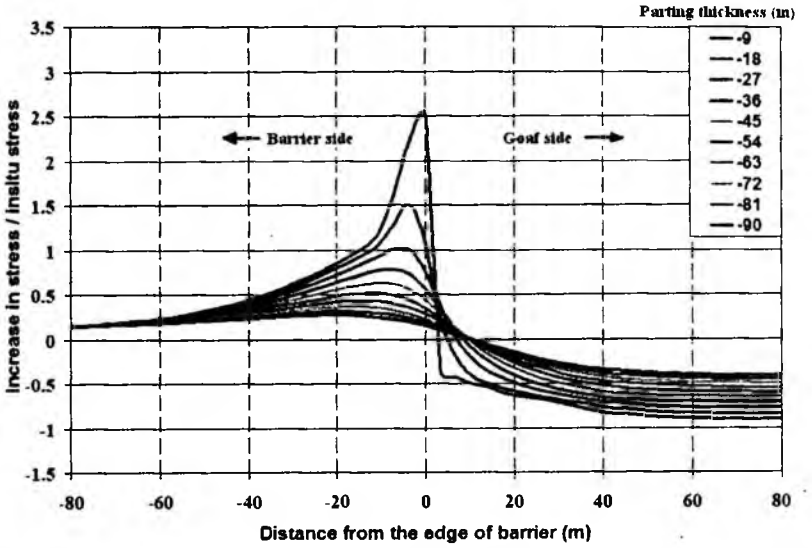

Fig. 3: Variation of stress in lower seam with top seam at 100m depth

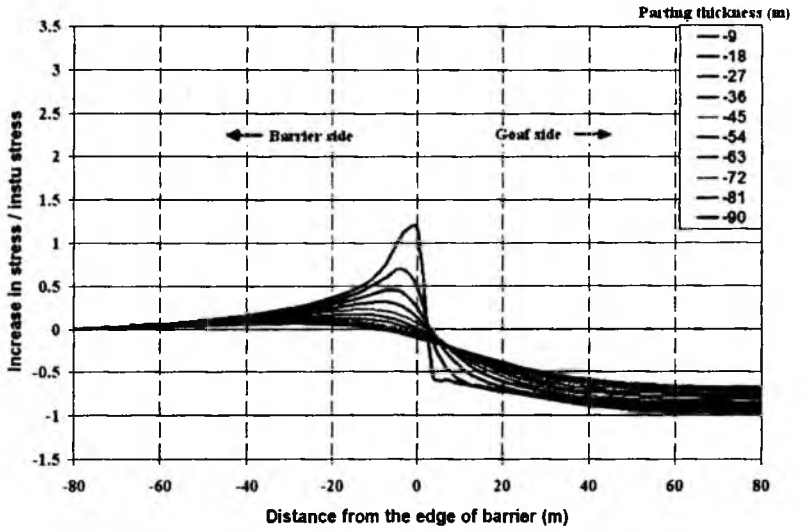

Fig. 4: Variation of stress in lower seam with top seam at 150m depth.

200m and 250m depths, were found similar (Figs. 3, 4, 5 and 6).

Magnitude of stress in section of seam lying below barrier reduced considerably as the depth of top seam increased (Table 2). Variation of stress in underlying seam was found maximum when the top seam was at 50m depth and it was found negligible at a depth of 250m. The effect of overlying workings on the stress distribution in lower seam was found to be insignificant when the parting thickness increased beyond 45m for all the depths. Results indicated that the influence of upper seam workings on lower seam was prominent for shallow depths of 50m and 100m and parting thickness of 9m to 45m.

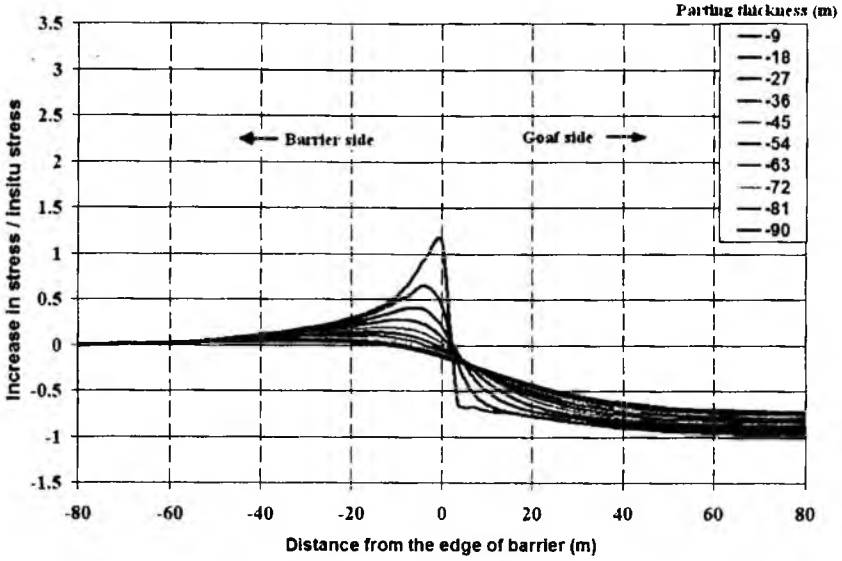

Fig. 5: Variation of stress in lower seam with top seam at 200m depth

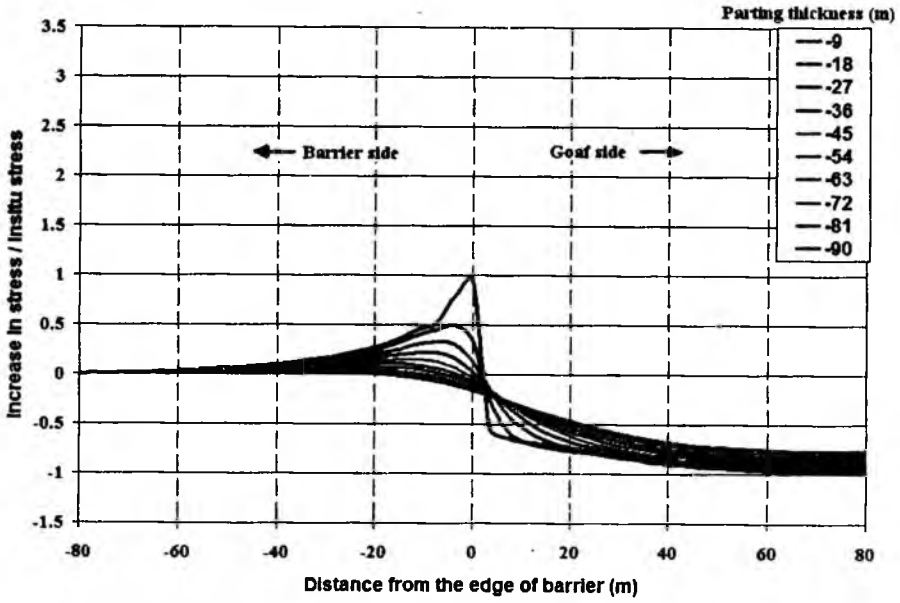

Fig. 6: Variation of stress in lower seam with top seam at 250m depth

Table 2: Increase in stress (above *in situ* stress) in lower seam

Depth of top seam (m)	Parting thickness				
	9m	18m	27m	36m	45m
50	3.1	1.78	1.16	0.83	0.65
100	2.5	1.5	1.0	0.8	0.62
150	1.17	0.7	0.5	0.3	0.23
200	1.14	0.65	0.40	0.27	0.20
250	0.93	0.50	0.33	0.22	0.15

Conclusions

Finite element analysis gave an insight over the stress redistribution occurring on the lower seam due to the extracted top seam. Results indicated that stress in lower seam lying under the barrier in top seam was higher as compared to the section lying under goaf. The zone of influence of barrier in upper seam was observed on the stress distribution in lower seam up to a distance of 20m from the barrier edge. This zone was found more predominant towards the barrier side than the locations below upper seam goaf. There was de-stressing of lower seam lying under goaf of top seam and the magnitude was found to be less than the *in situ* stress. Influence of upper seam workings on lower seam was significant for shallow depths of 50m to 100m and parting thickness of 9m to 45m. Thus, in case of undermining condition by longwall method, the barrier in lower seam should be offset by 10m from the barrier edge under the goaf of top seam in order to reduce the adverse effect of interaction of two seams.

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