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Evaluation of stability of underground workings for exploitation of an inclined coal seam by the ubiquitous joint model

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ABSTRACT

The effect of the inclination of strata and the coal seam on the stability of surrounding rock masses is evaluated by parametric study through numerical modelling. The ubiquitous joint model is used to consider the shearing effect of the bedding planes. The rock load height above the galleries is estimated by calculating the safety factor of immediate roof. It is obtained from the study that the rock load height and stress concentration are comparatively more at the dip side of the working than the rise side. The pillar strength is minimum when the inclination of the coal seam is close to $(\pi/4 + \phi_j/2)$ where ϕ_j is the friction angle of the bedding plane. A case study of inclined Jarangdih new seam (10' seam) of Sawang Colliery of Central Coalfields Limited (CCL) in India is presented. The inclination of the coal seam is around 1 in 3. As the coal seam is developed along the apparent dip of 1 in 5, the coal pillars become rhombus shaped with acute angle of 40°. Both numerical modelling and field investigation reveal that the failure zone extends more toward the acute angle of the coal pillar. Thus, heavier support system is installed in the roof at the intersections near acute angles of the coal pillars. Support system is designed based on the rock load height. Extraction methodology including stability analysis has also been presented for depillaring of this inclined coal seam.

1. Introduction

Coal is the prime source of energy not only in India but also many countries in the world. As the energy demand has increased significantly during the past decades, its production and productivity should also to be increased to reduce the gap between demand and supply. Though, the opencast coal mining method is the dominant mode of extraction of coal in India including some other countries in the world due to its high productivity, but it has many concerns including environmental issues. It is also not feasible to extract the coal reserves situated at the higher depth of cover[1] by opencast mining due to economical and geotechnical reasons. Therefore, underground mining method is a suitable option to extract the coal although it encounters severe geo-mining challenges.[2–7] Underground coal mining needs large-scale mechanisation for improvement of production and productivity which are generally found poor in comparison to opencast mining. One of the most difficult geo-mining problems faced during underground mining is the effect of discontinuities present in the coal seam and surrounding strata. High gradient of the coal seam makes the underground mining difficult. Extraction of an inclined coal seam by underground mining itself involves a number of geotechnical and operational issues. Mechanised extraction of an inclined coal seam is a major challenge to underground mining industry. Many issues like pillar instability, operational inconvenience, possibility of skidding of machines including highly asymmetrical redistribution of abutment stress and tendency to shear along bedding planes are to be addressed during design of mechanised extraction methodology of an inclined coal seam. These issues are mostly due to the effect of inclination and presence of discontinuities of the coal seam and surrounding strata formation. Thus, due consideration is needed for design of extraction methodology of an inclined coal seam.

Discontinuities are present in the coal seams and the overlying strata as weakness planes which generally control the strength and deformation behavior of the rock masses.[8,9] At shallow depth of cover, the rock mass contains more discontinuities than higher depth of cover.[10,11] These discontinuities exist in the coal seams in various forms like minor discontinuities, usually referred to as cleats,[12,13] usually occur in two orthogonal sets, with one of the sets being better developed than the other; and major discontinuities which extend over several meters in the strike direction. The major discontinuities are often generally referred to as slips and faults, and are responsible for catastrophic failure of the roof and/or pillar.[14,15] Slips may be wavy and undulating with weak in-filling up to several centimeters thick. These are seldom found in specific sets, but are randomly distributed in

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orientation. Sometimes a rock mass contains a number of joint sets which may dip at any inclination and usually extend from the roof to the floor of the excavation opening, but hardly extend into the surrounding strata.[16] Apart from these types of discontinuities, bedding planes[17] are generally found in the rock masses, especially in the sedimentary rock formation. In contrast to joints in the rocks, these bedding planes are comparatively smooth[18] and the shear strength is affected by the presence of water or moisture.[19,20] Therefore, excavations in such sedimentary rocks are associated with high risk. The characteristics of the bedding planes in the sedimentary rocks are somewhat different from the rock joints.[18] As the rock joints are not smooth, the shear strengths of the rock joints are dependent on the joint roughness coefficient (JRC) as well as the joint asperity strength.[21–22] Unlike the rock joints, bedding planes in the sedimentary rocks are comparatively smooth and persistent. Failure along these joints may be accompanied by the damage of the intact rock matrix. But, as the bedding planes in sedimentary rocks are persistent, failure is likely to be associated with the separation or sliding along its inclination. The friction angle (∅) for bedding planes in the sedimentary rocks can be susceptible to wetting, especially for shale and mudstone. It is found that the friction angle may reduce up to 50% due to wetting.

Due to the smoothness and wetting effect of the bedding planes, the shear strength reduces drastically. The problem is further aggravated when the mining activity is carried out in an inclined coal seam. Excavation of an inclined coal seam becomes risky due to the lateral movement of strata[23] along the bedding planes and the increase of the lateral stresses due to the shear component.[24] As the coal measures rocks are weak, these have the tendency to separate from the bedding planes. These rocks start sliding along their dip[25–26] due to the effect of their own weight, in-situ horizontal stresses and excavation. The existence of bedding planes alters the stress distribution pattern around an underground opening in comparison to an isotropic rock mass. This may result in different modes of rock mass failure around the opening compared with the modes observed in the isotropic rock masses.[27] Therefore, the failure of the coal pillar or roof strata becomes irregular. As the bedding planes of the roof strata are prone to slide,

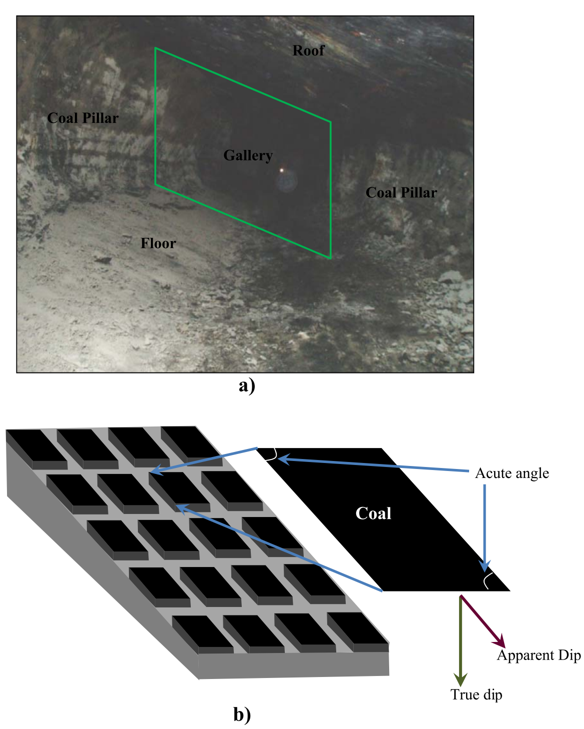

Fig. 1. (a) Inclination of the coal seam and the overlying strata. (b) Development of an inclined coal seam along the apparent dip.

they will exert high shearing effects on the support system[23] causing the instability of the roof. So, the consideration of bedding planes becomes utmost important to design the mining operation in an inclined coal seam. Several methods like in-situ testing, physical modelling, numerical simulation, etc. are used to know the effect of the inclination of bedding planes on the excavation. As the former two are generally costly and time consuming, numerical simulation is the most suitable way to evaluate the effect of inclination of bedding planes. Bedding planes or discontinuities are not usually used in continuum numerical simulation, rather their effects are considered by simply reducing the geotechnical properties of rock masses.[28,29] This method does not possibly represent the effects of the bedding planes in numerical modelling in a realistic way because the existence of the same significantly changes the stress distribution pattern[30] in the rock masses. In this paper, the effect of inclination of bedding planes on the working of an inclined coal seam is studied through numerical simulation by FLAC3D (Fast Lagrangian Analysis of Continua in 3 dimensions).[31] Here, bedding planes are modelled by ubiquitous joint model[32,33] which is an in-built constitutive model of FLAC3D. Parametric study is done to know the stress distribution and stability of the strata with respect to the inclination of the strata. One case study of inclined Jarangdih new seam (10′ seam) of Sawang Colliery of Central Coalfields Limited (CCL) in India has been discussed. The inclination of the coal seam is 1 in 3.15 and the immediate roof is shale. Stability analysis of the development and the depillaring operation is carried out through field investigation and numerical modelling.

2. Problems related to the inclined coal seam working

Working in an inclined coal seam (Fig. 1a) requires special attention due to the challenging geotechnical problems. Whenever a coal seam is inclined, the development along its true dip creates problem from operational point of view. Therefore, it is practiced to develop the coal seam along its apparent dip (Fig. 1b) to make the maneuvering of machineries convenient.[34] Due to this type of development, the coal pillars become rhombus shaped consisting two acute angled corners. As these corners are situated adjacent to the junction, stress is generally concentrated on these corners. The stress concentration is comparatively high at the corners having acute angle. This results in failure of the corners which in turn increases the area of junction. Therefore, the stability of the junction is an issue during the working of an inclined coal seam.

Due to the inclination of the strata, the bedding planes try to slide along the true dip. As the rock is weak in shear, there is a possibility of separation among the bedding planes. Therefore, the stability of the strata mainly depends on the shear strength of the bedding planes during extraction of an inclined coal seam. This problem is further aggravated when the water percolates from the roof. This creates additional pressure of water along the direction of sliding. The presence of water in the strata further reduces the shear strength of the bedding planes by decreasing the value of the friction angle. Apart from the strata control problems, the movement of men and machineries is affected by the inclination of the coal seam as there is a tendency to skid along the true dip. Therefore, the problems associated with the inclined coal seams as well as the inclined bedding planes of the roof strata need to be handled carefully during the extraction of an inclined coal seam.

3. Stress distribution in fracture zone of an inclined coal pillar

When a coal seam is inclined, the horizontal stress reduces the stability of the pillar by increasing the potential of sliding along the bedding planes. A simplified mathematical expression of stress distribution on an inclined coal pillar is presented below [35]. The assumptions are that the coal pillar is homogeneous, isotropic and